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Flight and Gun Setting for Side Firing Aircraft

by
Kenneth K. Cobb
and
Gerald Solomon

JULY 1966

AIR FORCE ARMAMENT LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
EGLIN AIR FORCE BASE, FLORIDA

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FOREWORD

This report was prepared by Air Force Armament Laboratory (AFATL) (ATBR), Eglin Air Force Base, Florida, under Project 2547, "Advanced Non-Nuclear Weapon Ballistics". The preliminary work was furnished to several interested agencies in November 1965.

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This technical report has been reviewed and is approved.

Edward F. Martin

for CHARLES E. WOOD
Lt Col, USAF
Chief, Ballistics Division

ABSTRACT

This report provides information on the sighting of side firing guns for different gun declinations, slant ranges, and altitudes. The information was generated and provided for use in the employment of the AC-47 MINI-gun system and for the design of the follow-on installations.

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CONTENTS

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GENERAL

The AC-47 MINI-gun system, as originally designed, was aimed nearly parallel to the lateral (wing line) of the aircraft. It was suggested in AMR 65-36 (September 1965) that for the desired firing conditions (altitude, true airspeed, and slant range) of the system, the aiming and maneuvering of the aircraft would be simplified by declinating the guns in order to put the gun line near the center of the turn. The required declination depends primarily on the aircraft altitude above ground level, the true airspeed, and to some extent, on the slant range. See figure on page 3. For the firing conditions of the AC-47 aircraft, a declination of about 13° is required.

A gun stand declination device was designed by Lt. Col. Lloyd Combs of SAWC in December 1965. Two gun pods were boresighted on a single aircraft which had the declinated stands set at 12° down. Capt. Lowell Kirkpatrick, who has considerable experience firing the gun from non-declinated stands, flew the missions to evaluate the system with declinated guns. He reported that the declinated gun system was easier to fly and it was more accurate. There was no difficulty in sighting the target.

Presently, the module (follow-on AC-47 gun stand) is being tested by APGC at Eglin AFB. A screw mechanism was added to this system to facilitate gun declination to 18°. One purpose of the module test is to establish the optimum declination angle for given firing conditions.

This report gives curves and data on the sighting and flight characteristics for the MINI-gun side firing aircraft for different gun declinations, slant ranges, and altitudes. These data were generated as indicated in Appendix I.

DEFINITIONS

1. Bank Angle (θ) - The vertical angle from the horizontal to the wing line, lateral axis of aircraft.

2. Center Angle (ϕ) - The vertical angle from the horizontal to the center of the turn.

3. Gun Line - A line perpendicular to the longitudinal axis of the aircraft and in the declinated lateral plane of the gun.

4. Gun Angle (ϕ_g) - The vertical angle from the horizontal to the gun line, lateral plane of gun.

5. Slant Range (SR) - The line distance from the aircraft to the target.

EXPLANATION OF CURVES

Curve Set I (Figures 1 - 6) gives the true airspeed necessary to bring the gun line on the center of the turn for declination angles of 0°, 5°, 10°, 12°, 14,° and 16°. For each gun declination angle except 0° there is a slight dependence on slant range. For 0° gun declination the true airspeed necessary to keep the guns on the center of the turn depends only on the altitude above ground level.

From the curves it is seen that a gun declination of 14° gives good performance. This allows the pilot to keep the guns nearly on the center of the turn between altitudes (AGL) of 2000 to 4000 ft by varying the true airspeed between 100 and 164 kt. The gun declination provides a gun line slightly above the center of the turn and allows for a drop of about 1.25° (22 mils) for the following conditions: altitude 3000 ft, TAS 142 kt, gun angle 42° and bank angle of 28°. For the original AC-47 system, the sighting point on the boresight frame was set for 130 kt. If the guns are fired at an airspeed exceeding that for which they were boresighted the sighting point must be moved forward about .625 mil/kt.

Curve Set II (Figures 7 - 11) gives the same data as the first set. In Set II each figure is for a given slant range with different curves representing gun declination of 0°, 5°, 10°, 12°, 14°, 16°, and 20°.

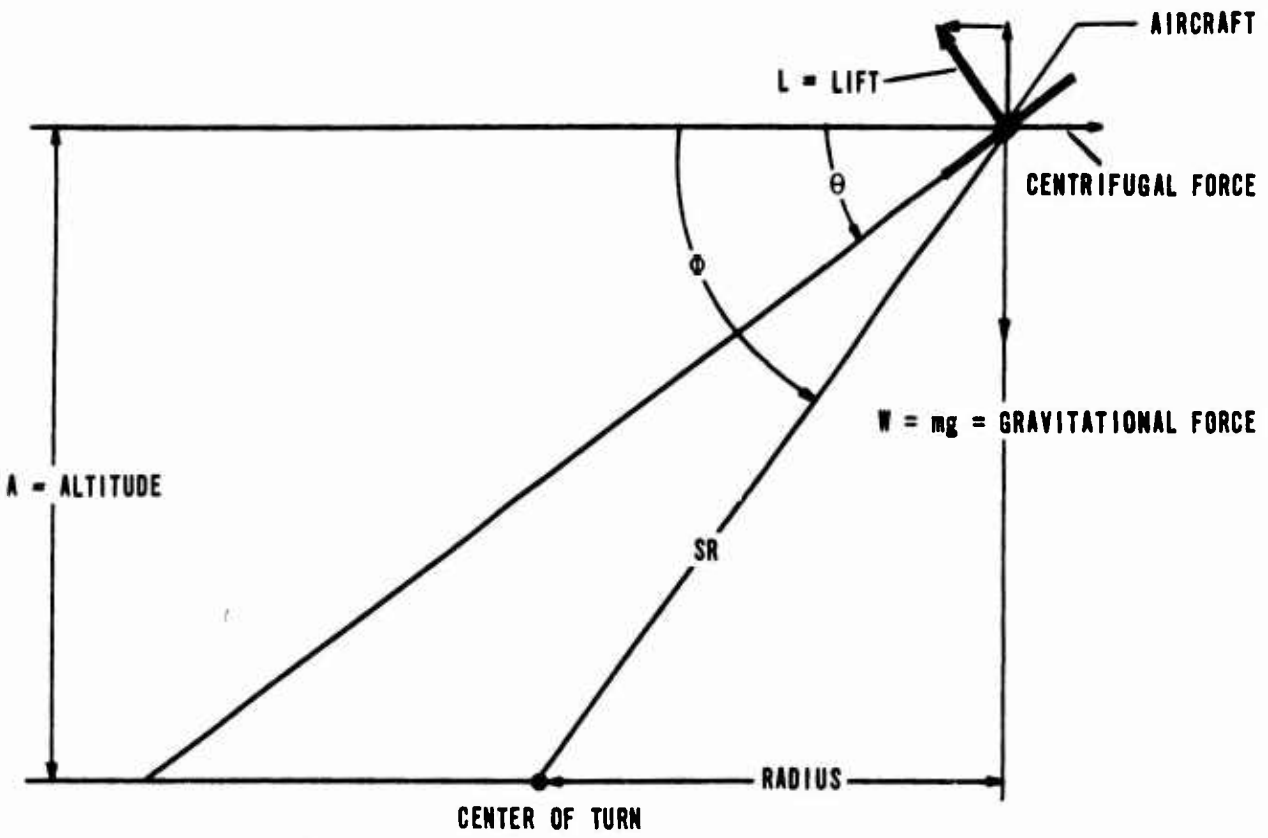
Curve Set III (Figures 12 - 31) are useful once the guns are fixed. This set gives the true airspeed necessary to bear the guns or the sight on the center of the turn for a given gun declination. The top (solid) line gives the true airspeed necessary to keep the gun line on the target (center of turn). The lower dashed line gives the true airspeed to keep the guns above the center of the turn by the amount of the projectile drop. That is, for each altitude there is a fixed gun angle for the fixed slant range. The sight is declinated below the gun line by the amount of the gravity drop at each altitude. The lower (dashed) curve then gives the true airspeed to keep the sight on center of the turn (target).

The true airspeed is plotted versus altitude AGL. The altitude AGL corresponds to a set bank angle (and gun angle) for the given slant range and gun declination. Also plotted, along the abscissa of the curve, are the gun angle, the bank angle corresponding to the altitude, the slant range to the target and the mil drop corresponding to the slant range and gun angle.

An example of the use of Curve Set III follows: Suppose the gun declination is 12°, and the pilot desires to open fire at 4500 ft SR from 3000 ft AGL (see Figure 24, reading under 3000 ft). We find a bank angle of about 30°, a gun angle of about 42°, and a mil drop of about 22 mils. Reading up to the dashed

curve, we find a true airspeed of 144 kt. With this bank angle, altitude, and true airspeed, the aim point is at the center of the turn and the guns are slightly above the center of the turn to account for the projectile drop. It is assumed that the sight is declinated below the gun line to account for the gravity drop.

Curve Set IV (Figures 32 - 51) shows the required bank angle to keep the slant range to the center of the turn constant for a given true airspeed and altitude above ground level. The dashed curve in this curve set gives the angle from the horizontal to the center of the turn. The two upper solid curves give the angle from the horizontal to the gun line for specified declination angles. Refer to figure below.



CONSIDERING FORCES ON AIRCRAFT AND GEOMETRY FOR LEVEL TURN. IT CAN BE SHOWN

$$\text{Tan } \theta = \frac{V^2}{gA} \quad \text{Tan } \Phi = \frac{V^2}{gA}\left(\frac{SR^2}{A^2} - 1\right)^{\frac{1}{2}}$$

V = SPEED OF AIRCRAFT

Physical Characteristics for Side Firing Aircraft.

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CURVE SET I

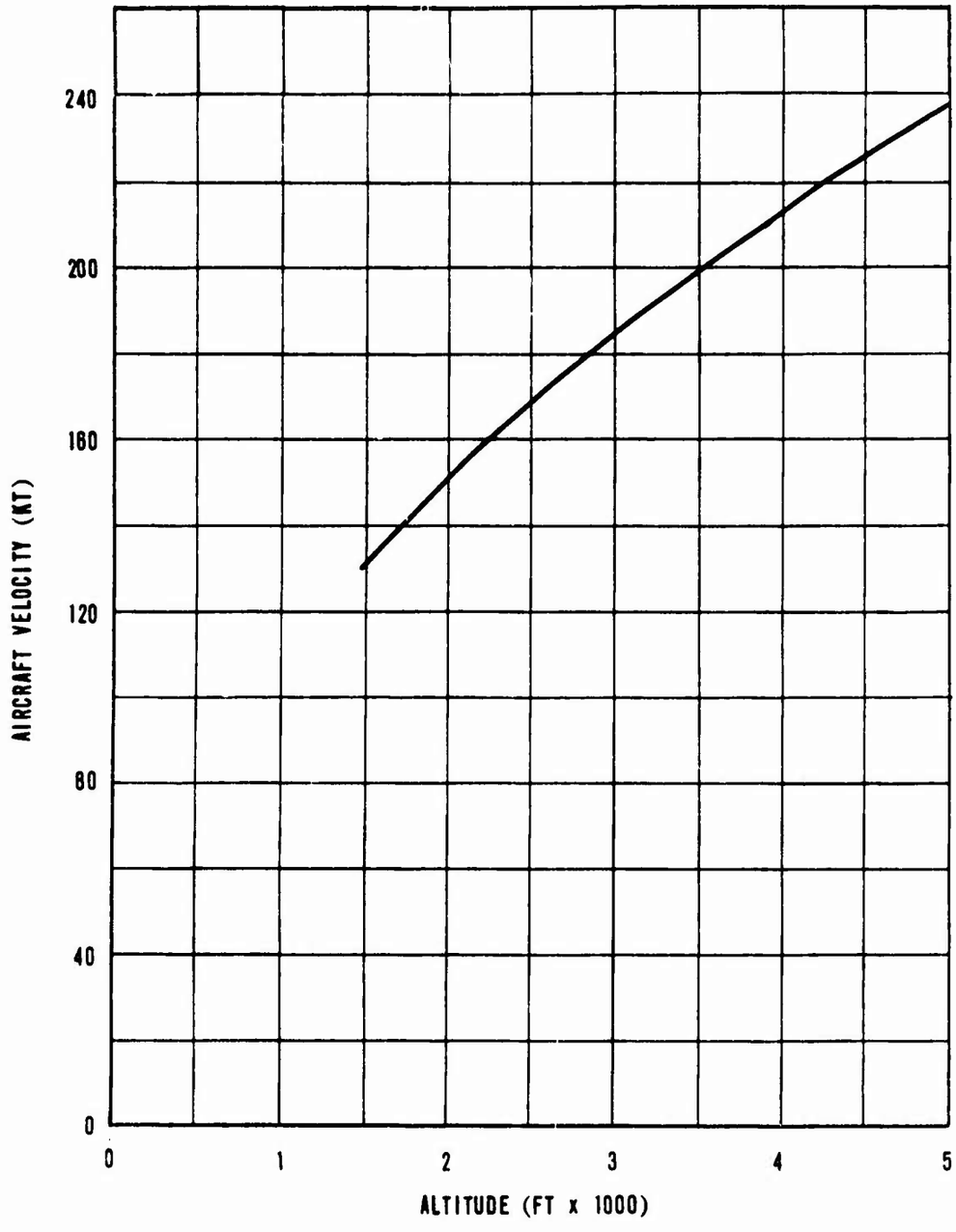

Figure 1. True Airspeed Necessary to Have Gun Line on Center of Turn, Gun Declination 0°. Valid for All Slant Ranges.

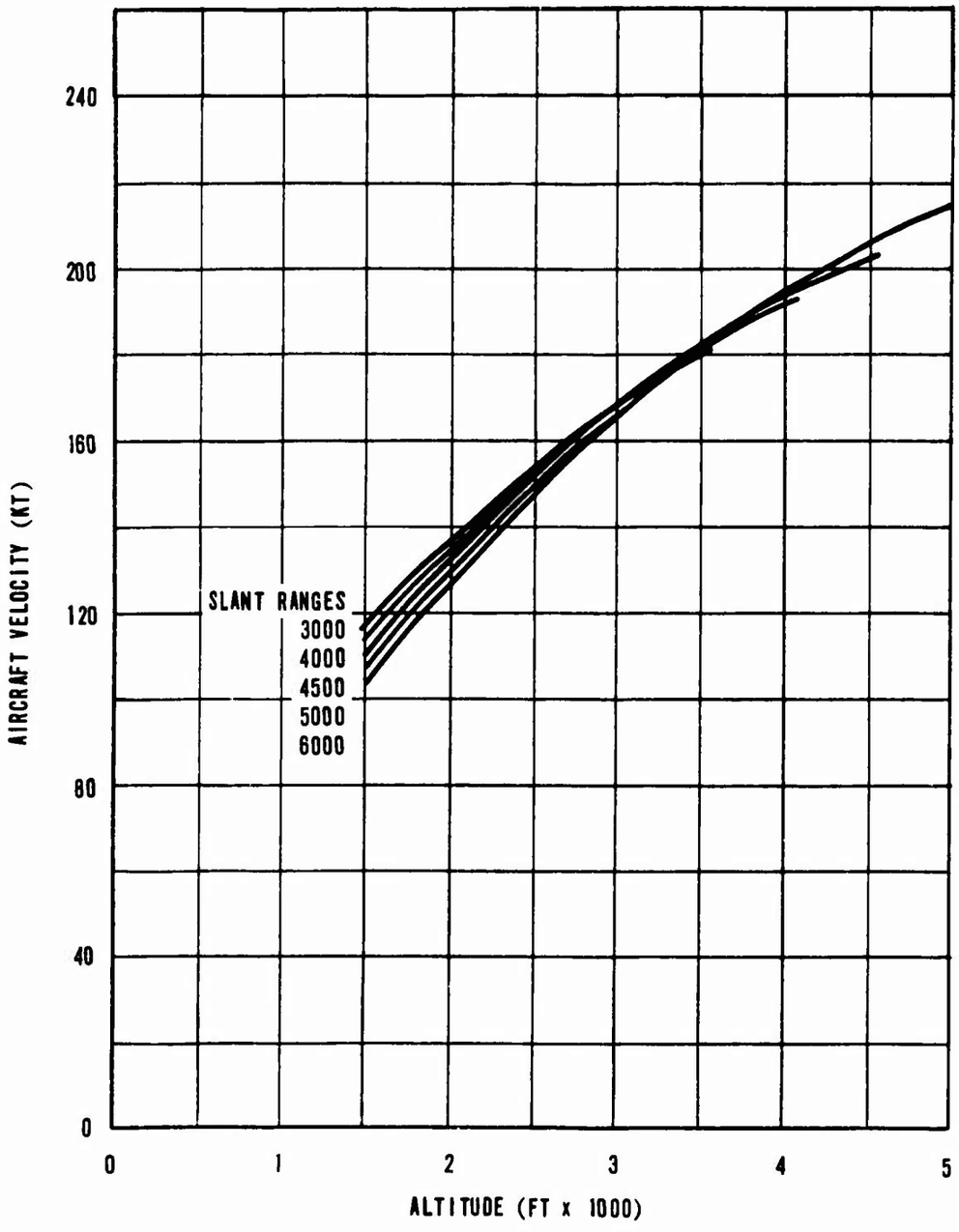

Figure 2. True Airspeed Necessary to Have Gun Line on Center of Turn, Gun Declination 5°.

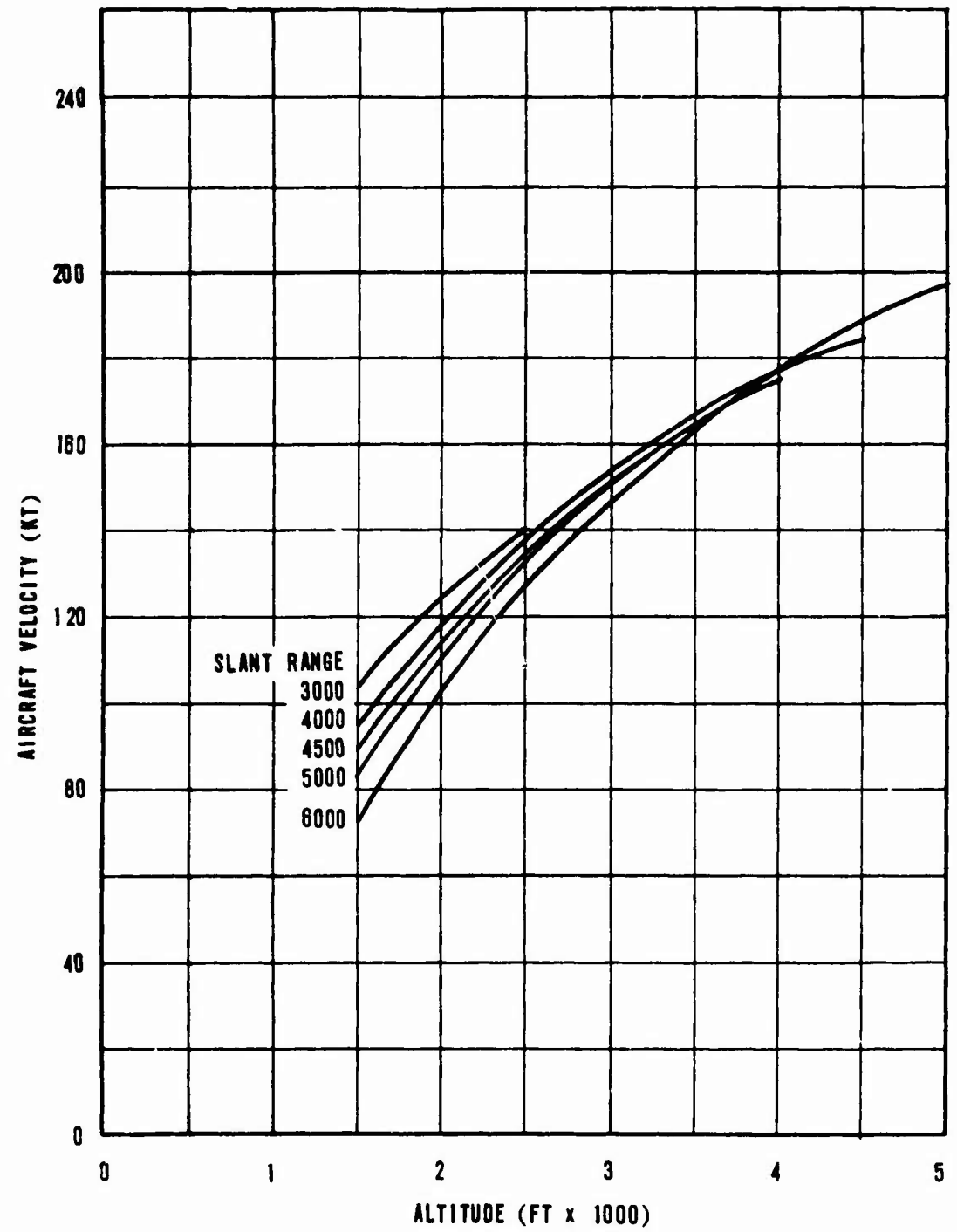

Figure 3. True Airspeed Necessary to Have Gun Line on Center of Turn. Gun Declination 10°.

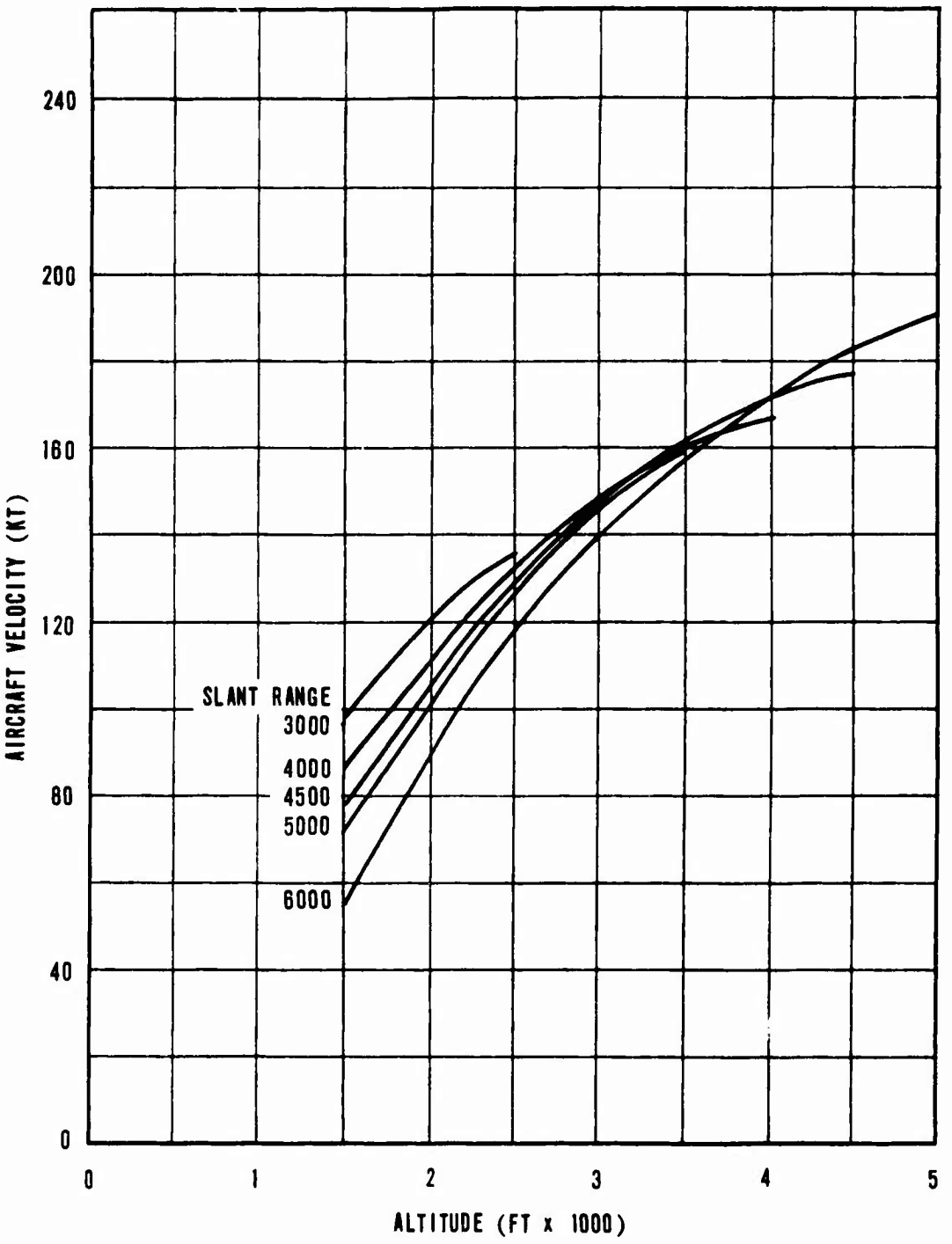

Figure 4. True Airspeed Necessary to Have Gun Line on Center of Turn. Gun Declination 12°.

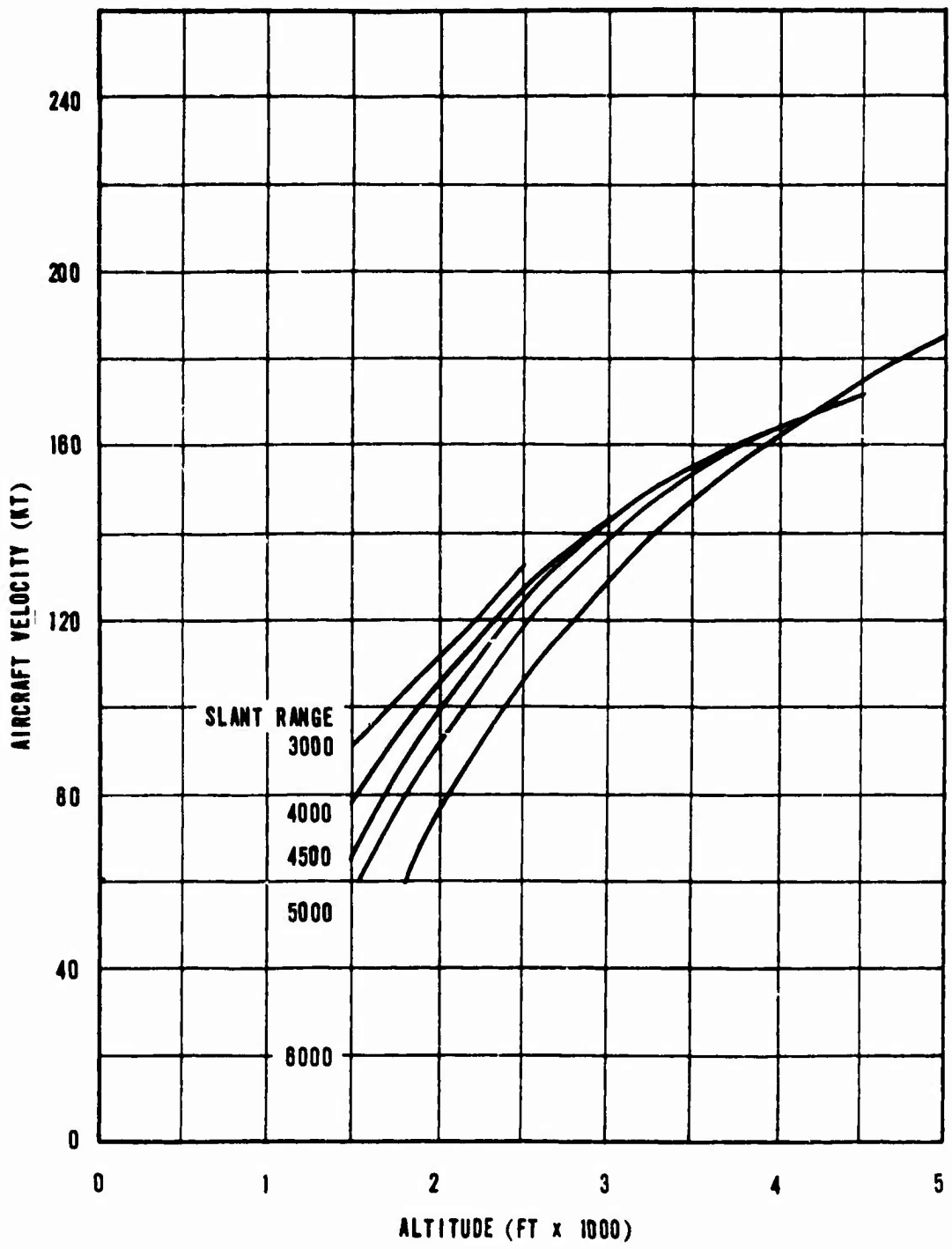

Figure 5. True Airspeed Necessary to Have Gun Line on Center of Turn, Gun Declination 14°.

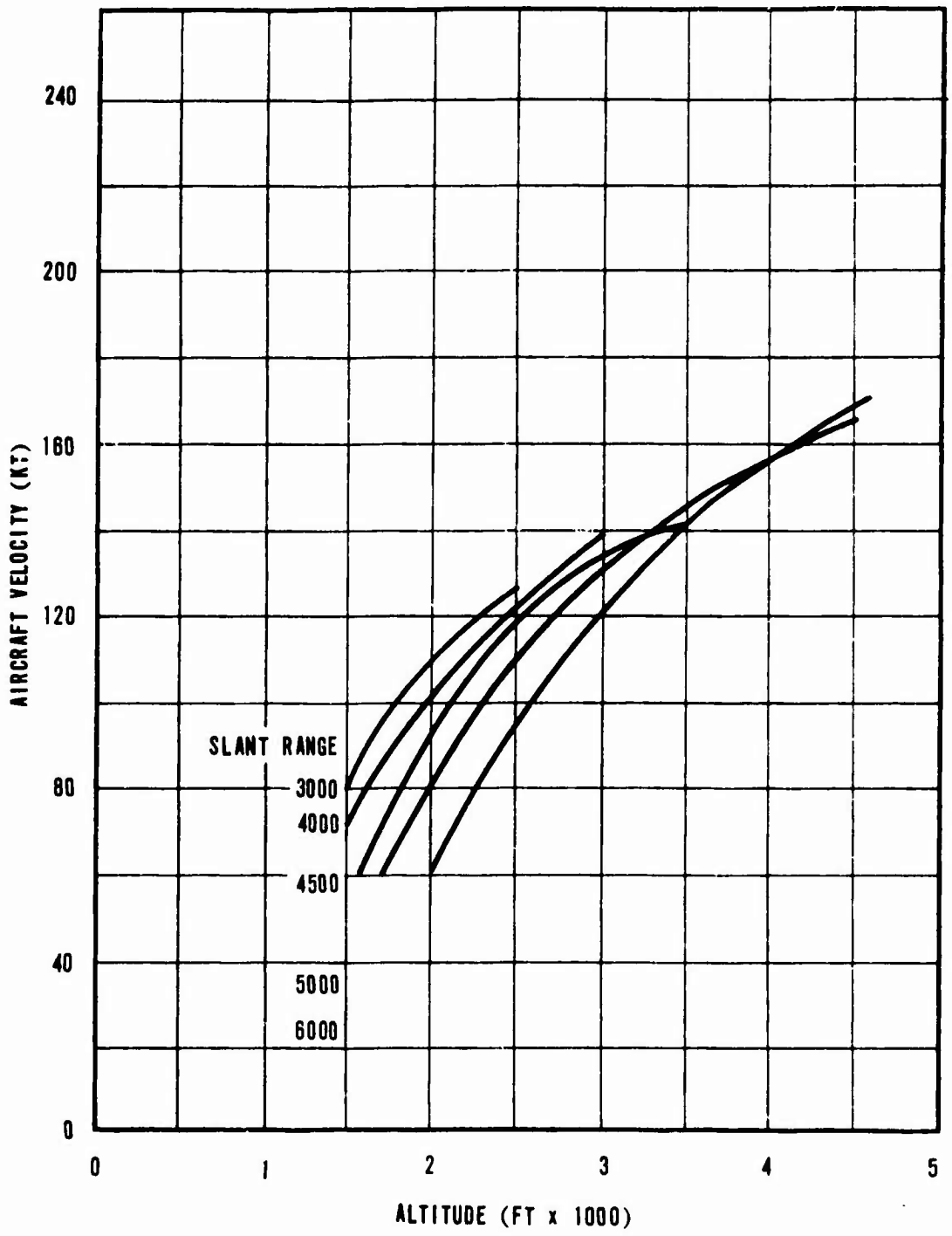

Figure 6. True Airspeed Necessary to Have Gun Line on Center of Turn. Gun Declination 16°.

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CURVE SET II

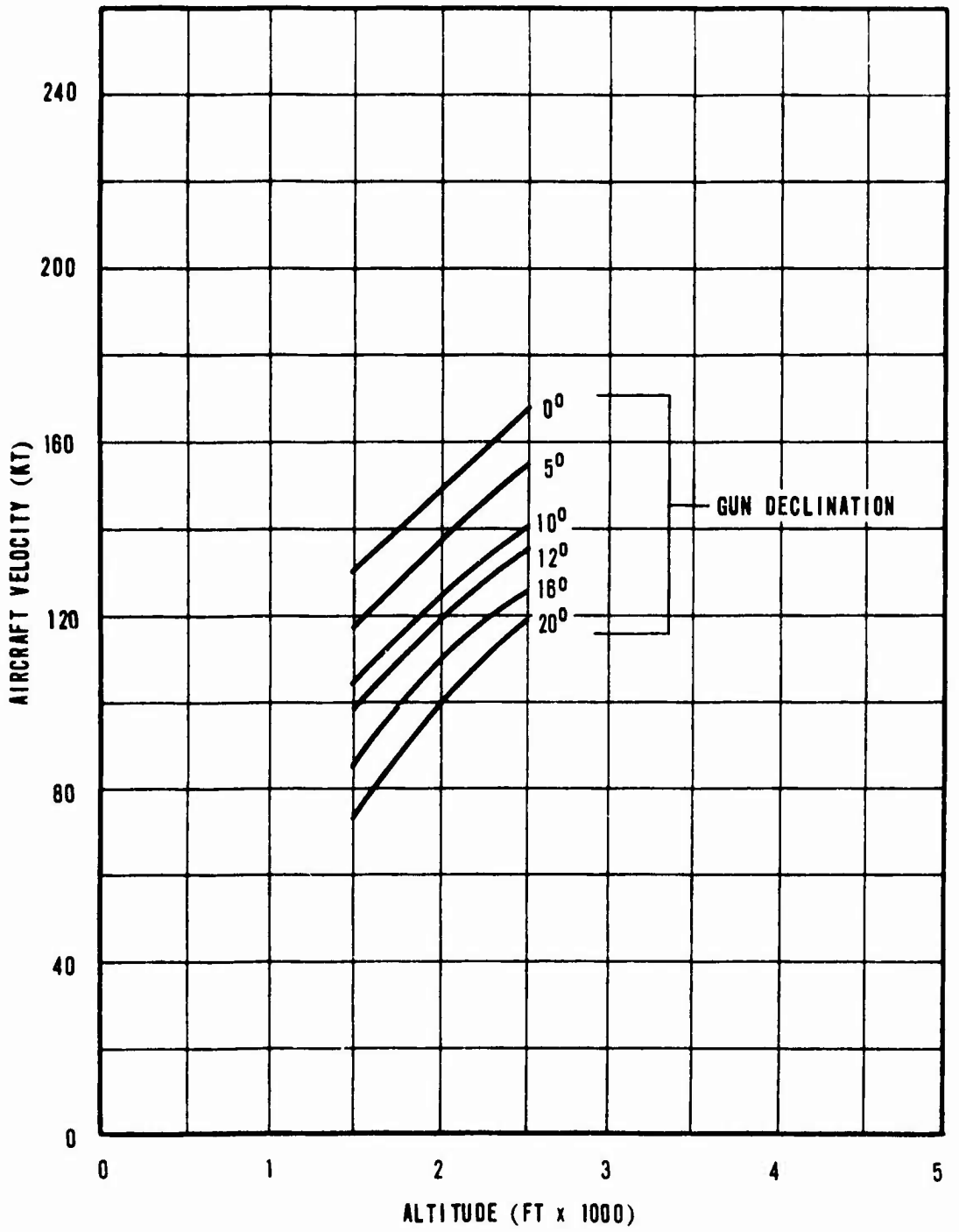


Figure 7. True Airspeed Necessary to Have Gun Line on Center of Turn. Slant Range 3000 Ft.

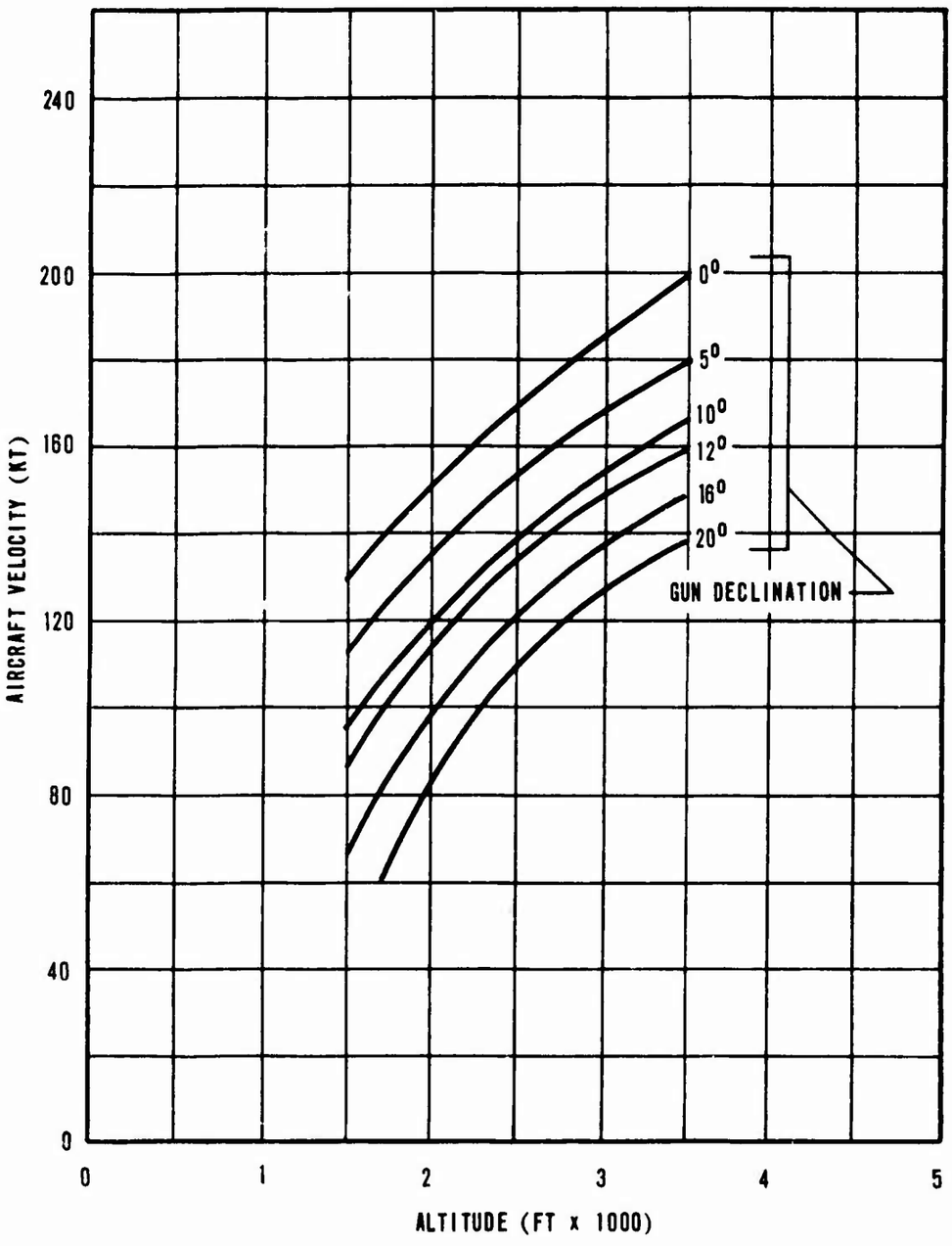


Figure 8. True Airspeed Necessary to Have Gun Line on Center of Turn. Slant Range 4000 Ft.

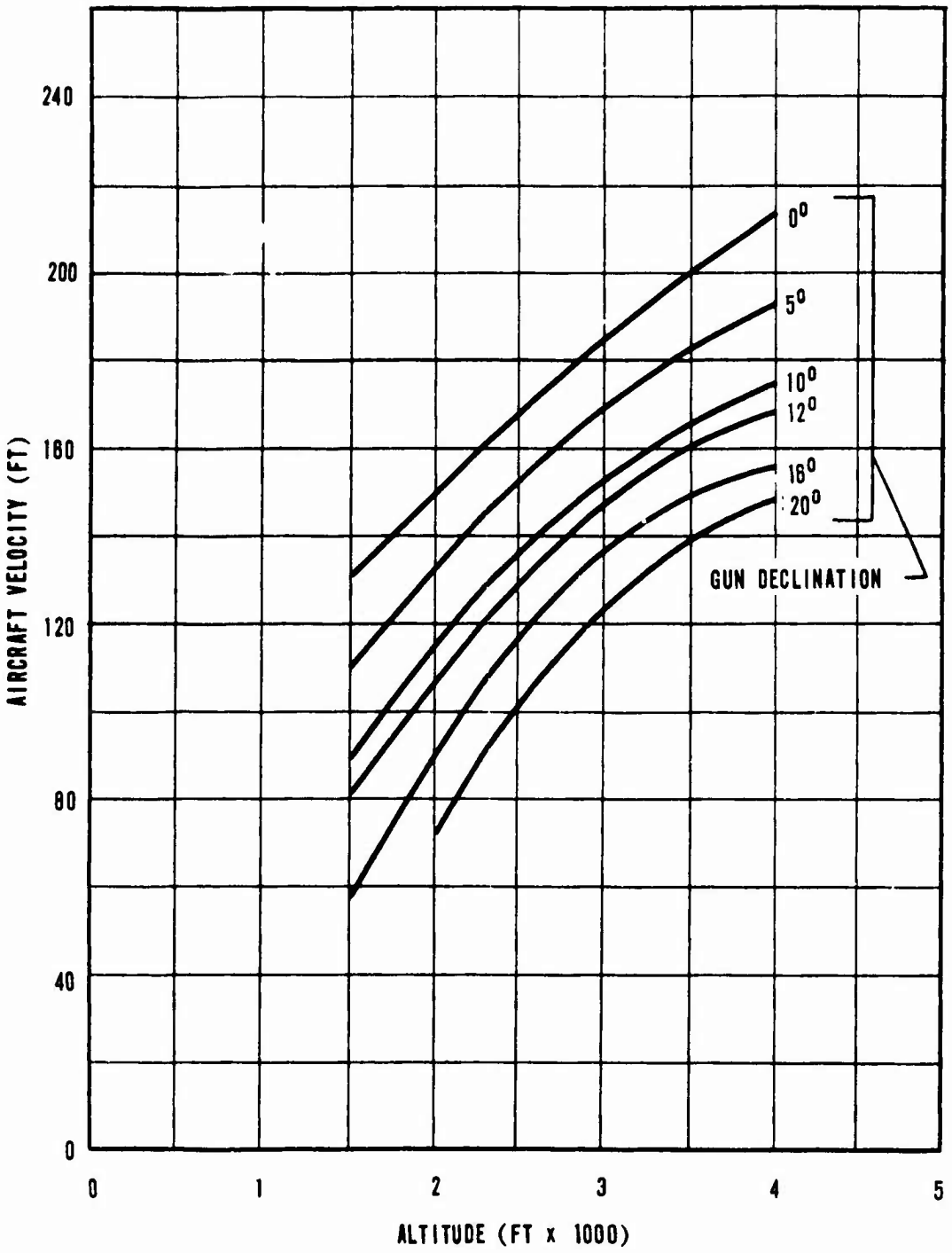


Figure 9. True Airspeed Necessary to Have Gun Line on Center of Turn, Slant Range 4500 Ft.

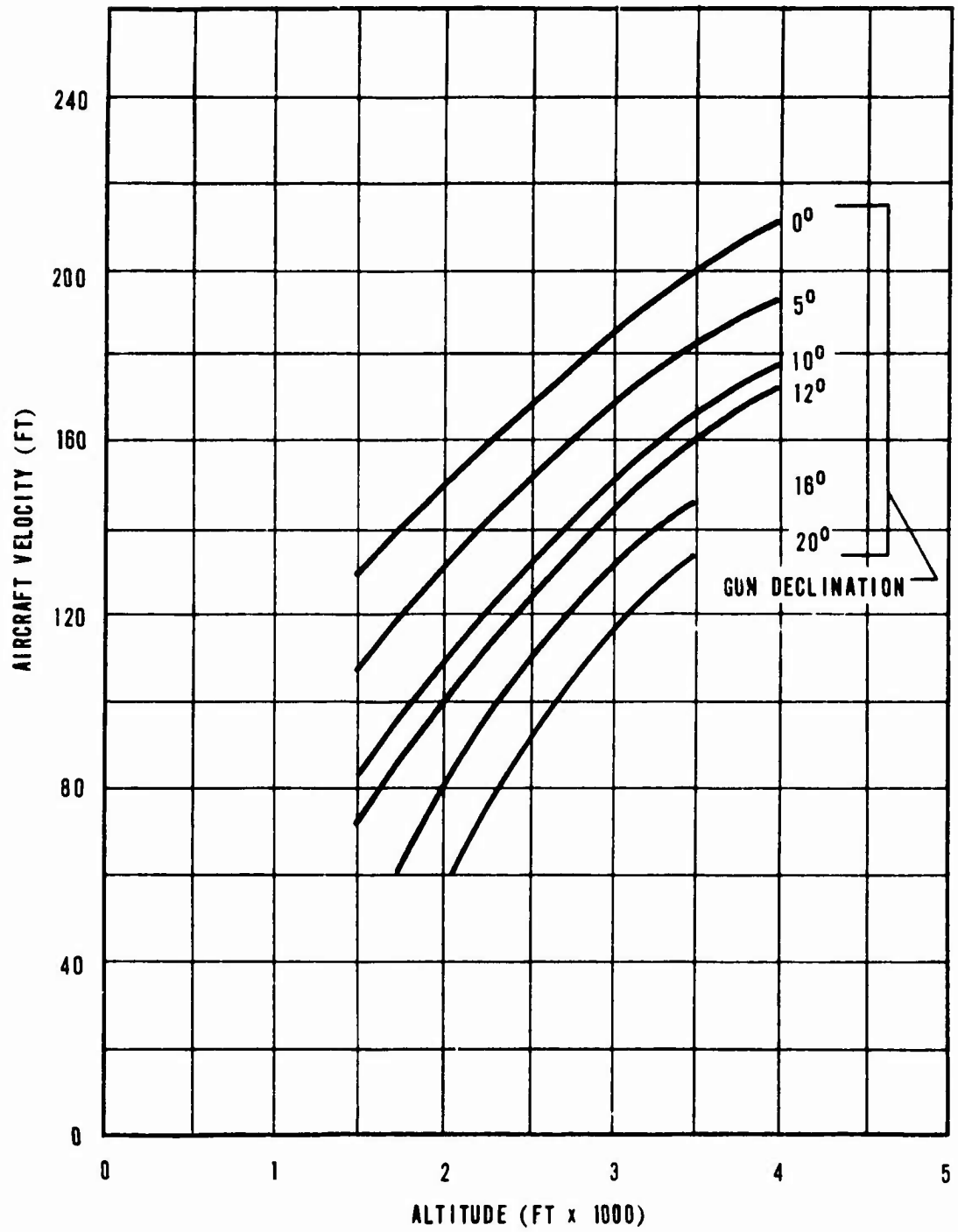


Figure 10. True Airspeed Necessary to Have Gun Line on Center of Turn, Slant Range 5000 Ft.

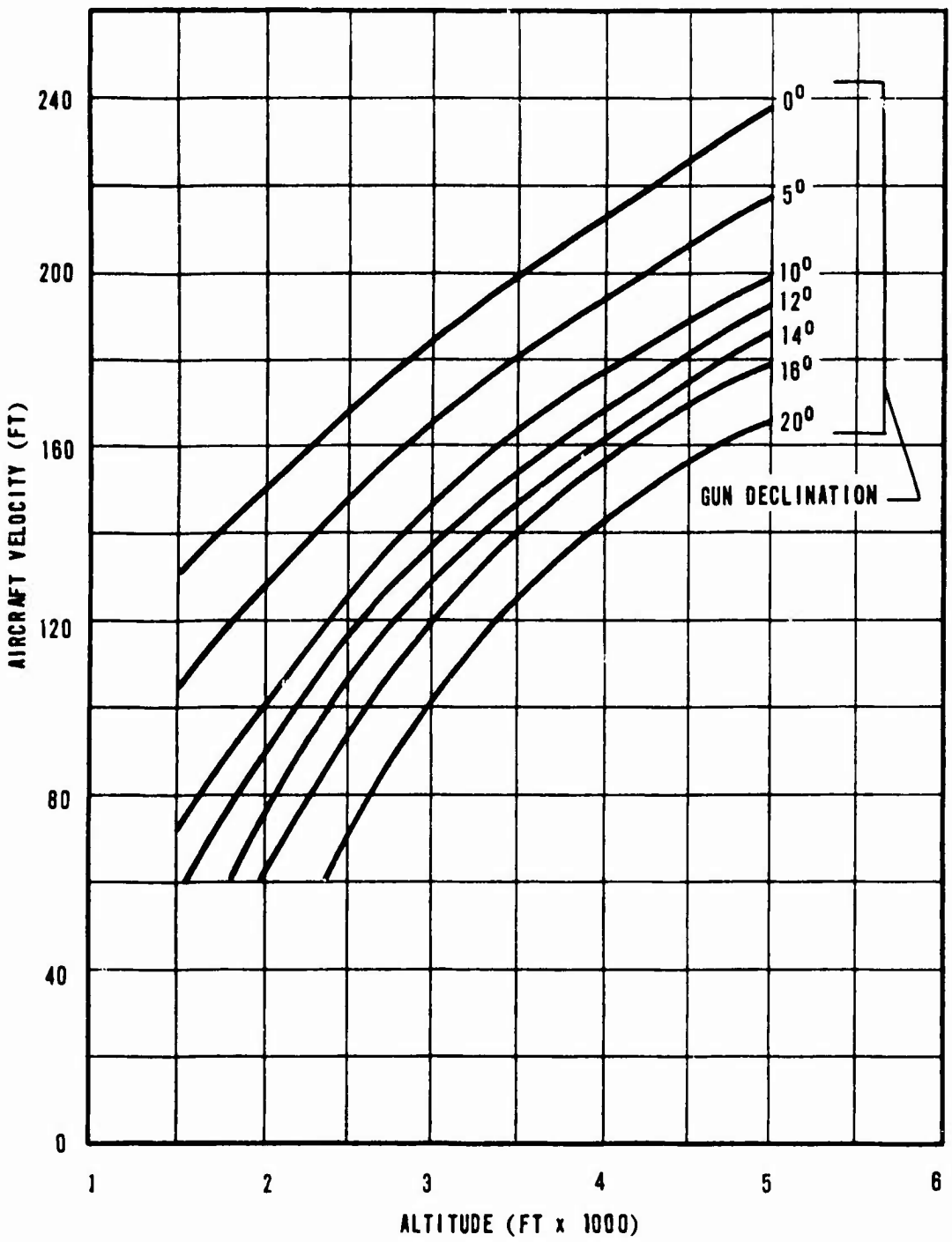


Figure 11. True Airspeed Necessary to Have Gun Line on Center of Turn. Slant Range 6000 Ft.

CURVE SET III

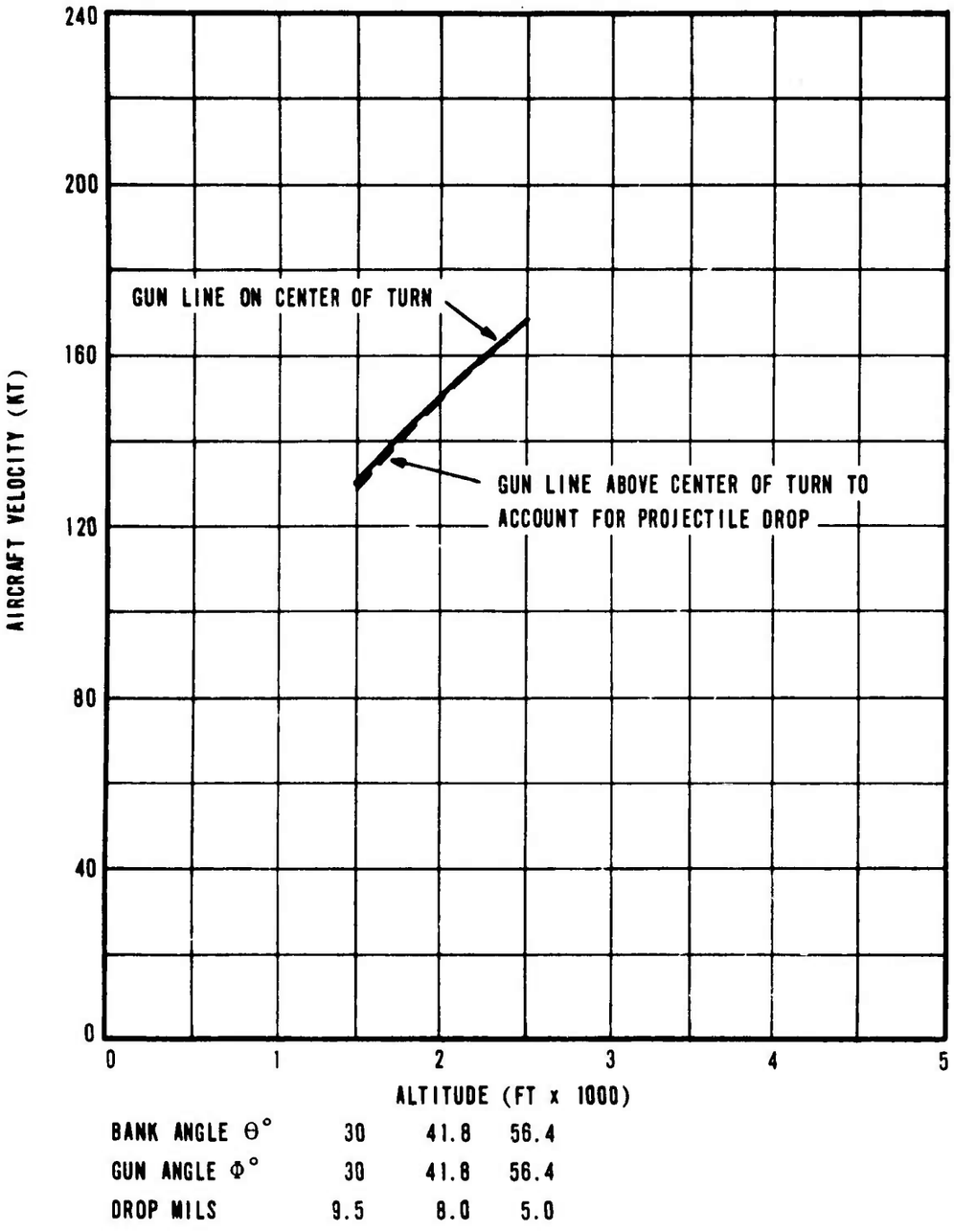
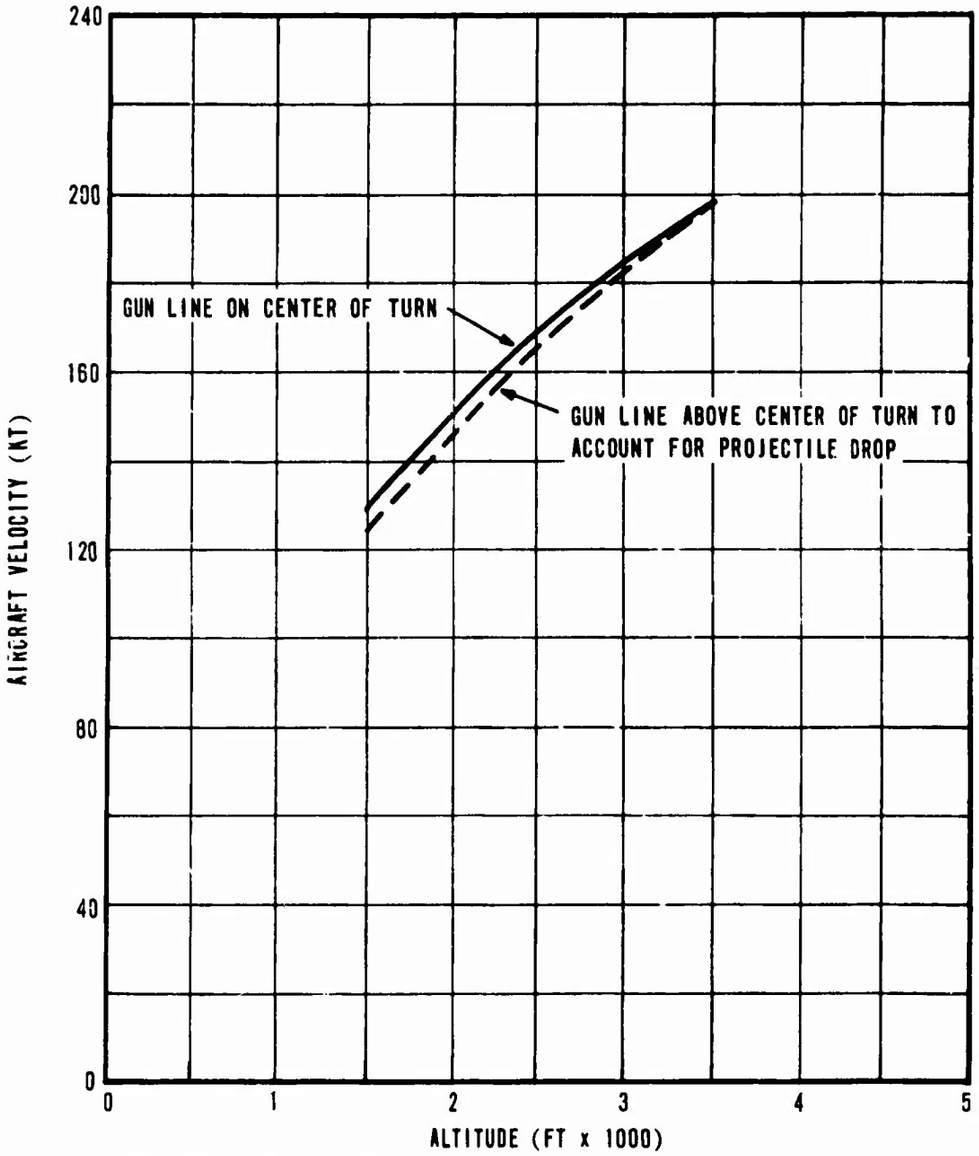
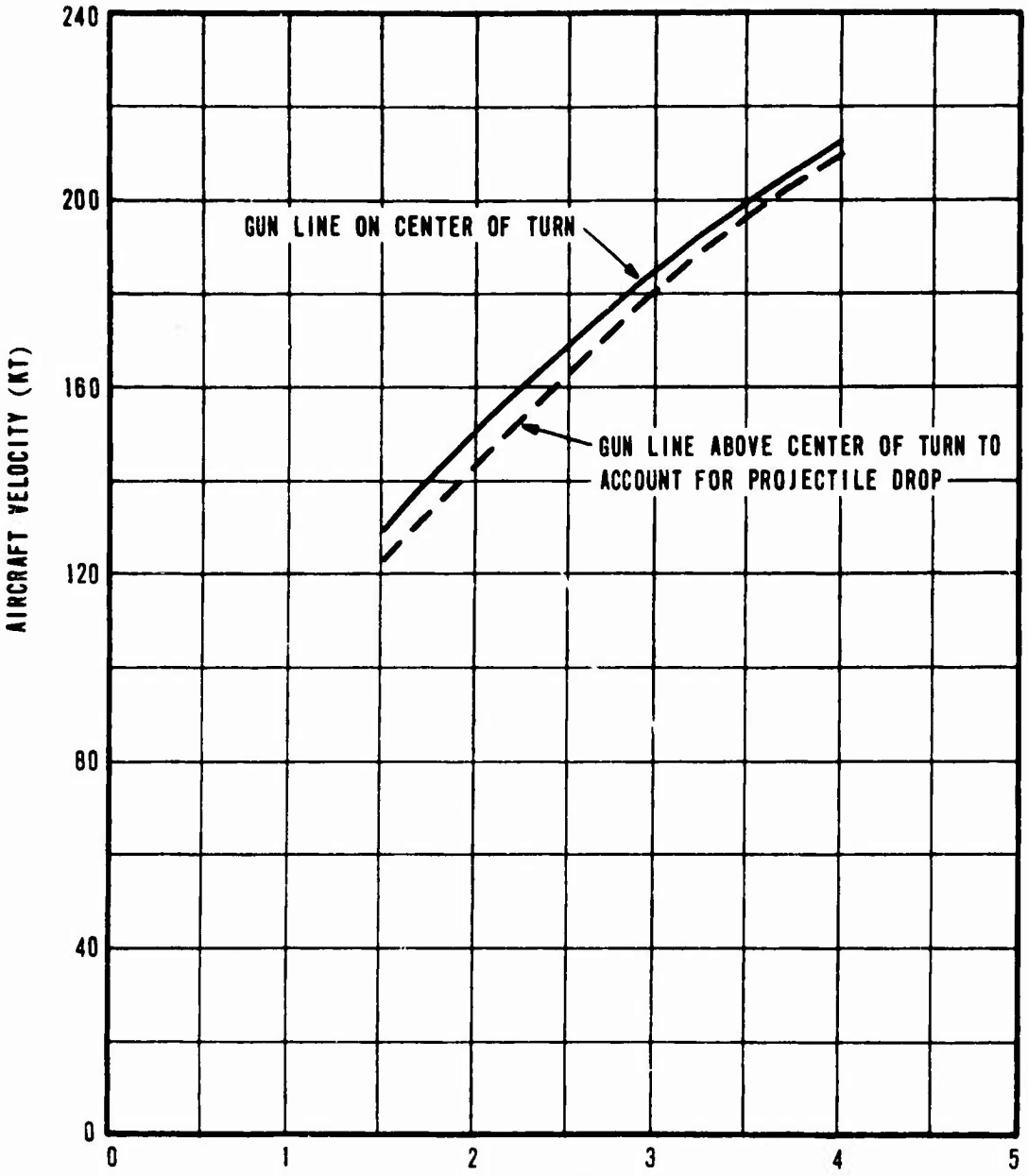


Figure 12. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn, Gun Declination 0°, Slant Range 3000 Ft.



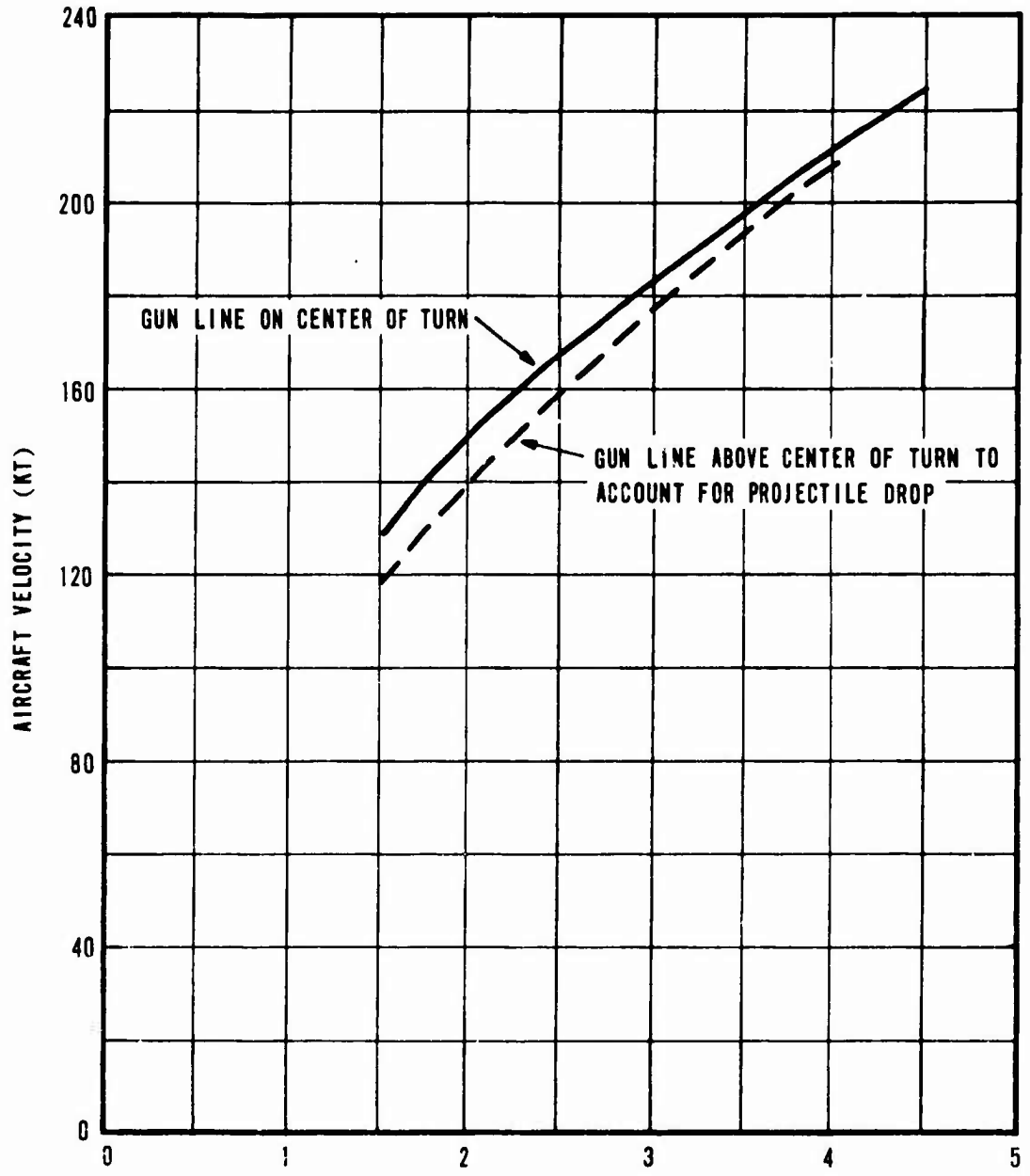
BANK ANGLE θ°	22	30	38.7	48.6	61
GUN ANGLE Φ°	22	30	38.7	48.6	61
DROP MILS	20	19.5	16.5	13.0	9

Figure 13. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 0°, Slant Range 4000 Ft.



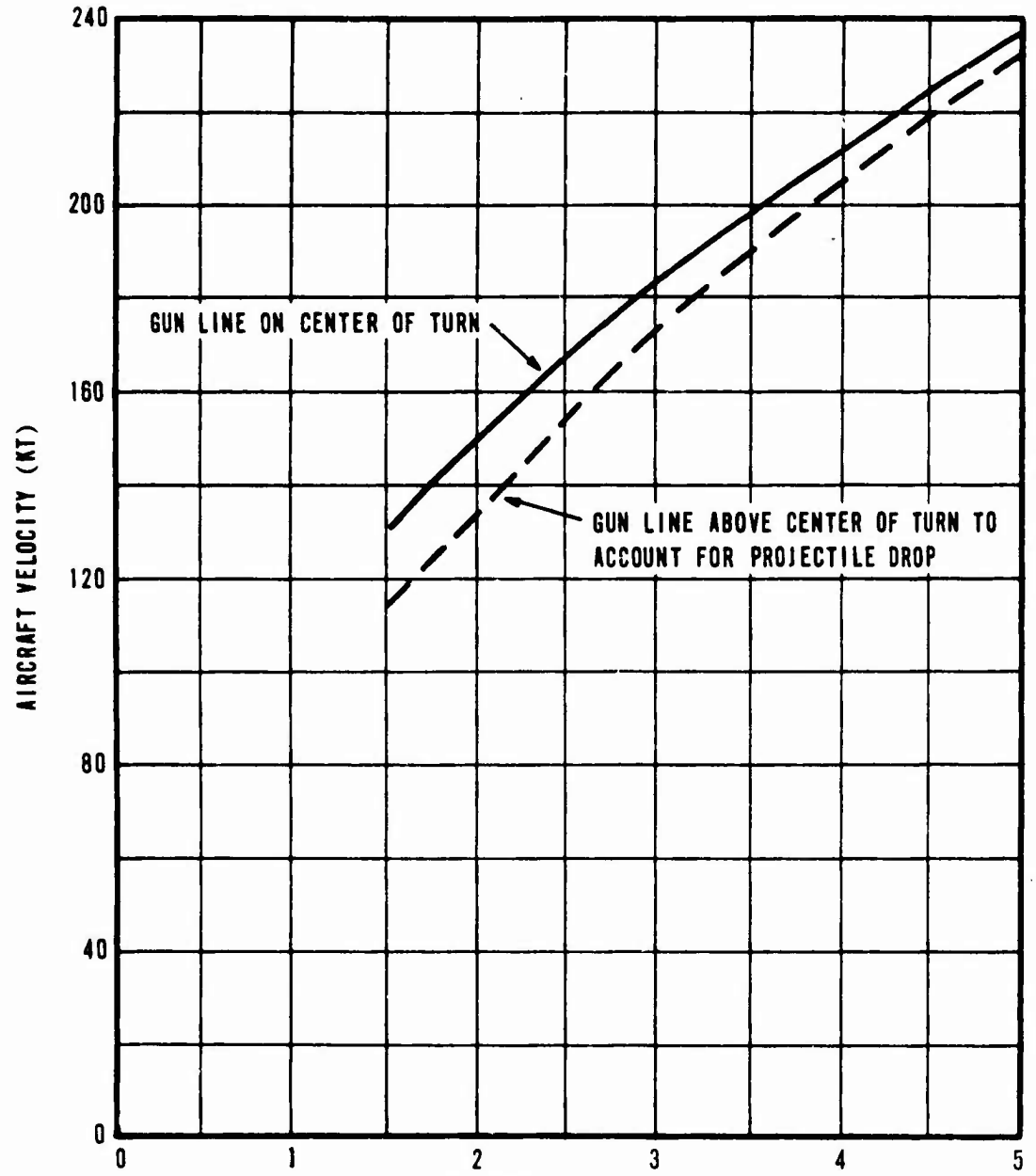
BANK ANGLE $\theta°$	19.5	26.4	33.9	41.8	51	62.7
GUN ANGLE $\Phi°$	19.5	26.4	83.7	41.8	51	62.7
DROP MILS	28	17	24	22	12	11

Figure 14. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 0°, Slant Range 4500 Ft.



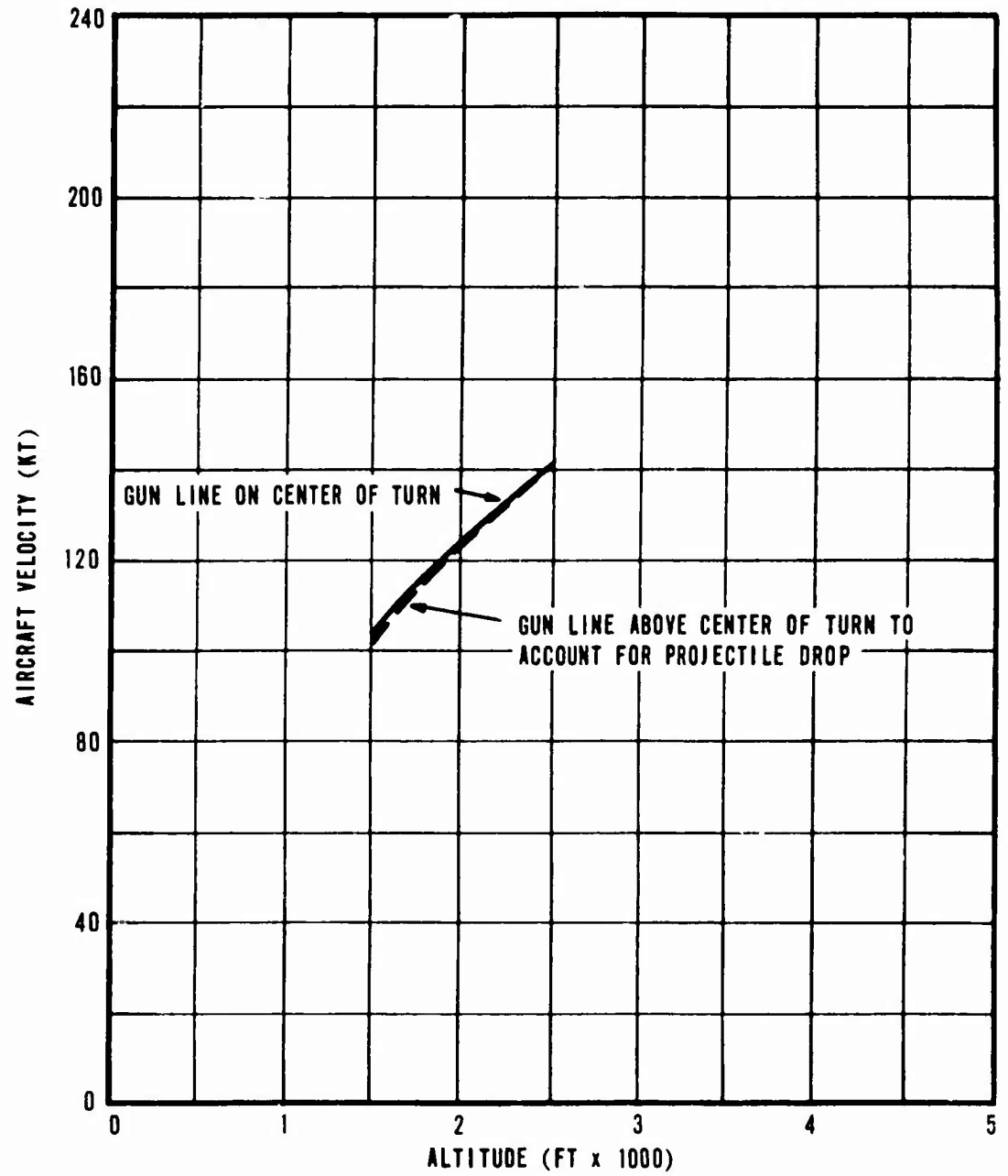
BANK ANGLE θ°	17.5	23.6	30	36.9	44.4	53.1	64.1
GUN ANGLE Φ°	17.5	23.6	30	36.9	44.4	53.1	64.1
DROP MILS	37	35	33	30	25	20	15

Figure 15. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 0°, Slant Range 5000 Ft.



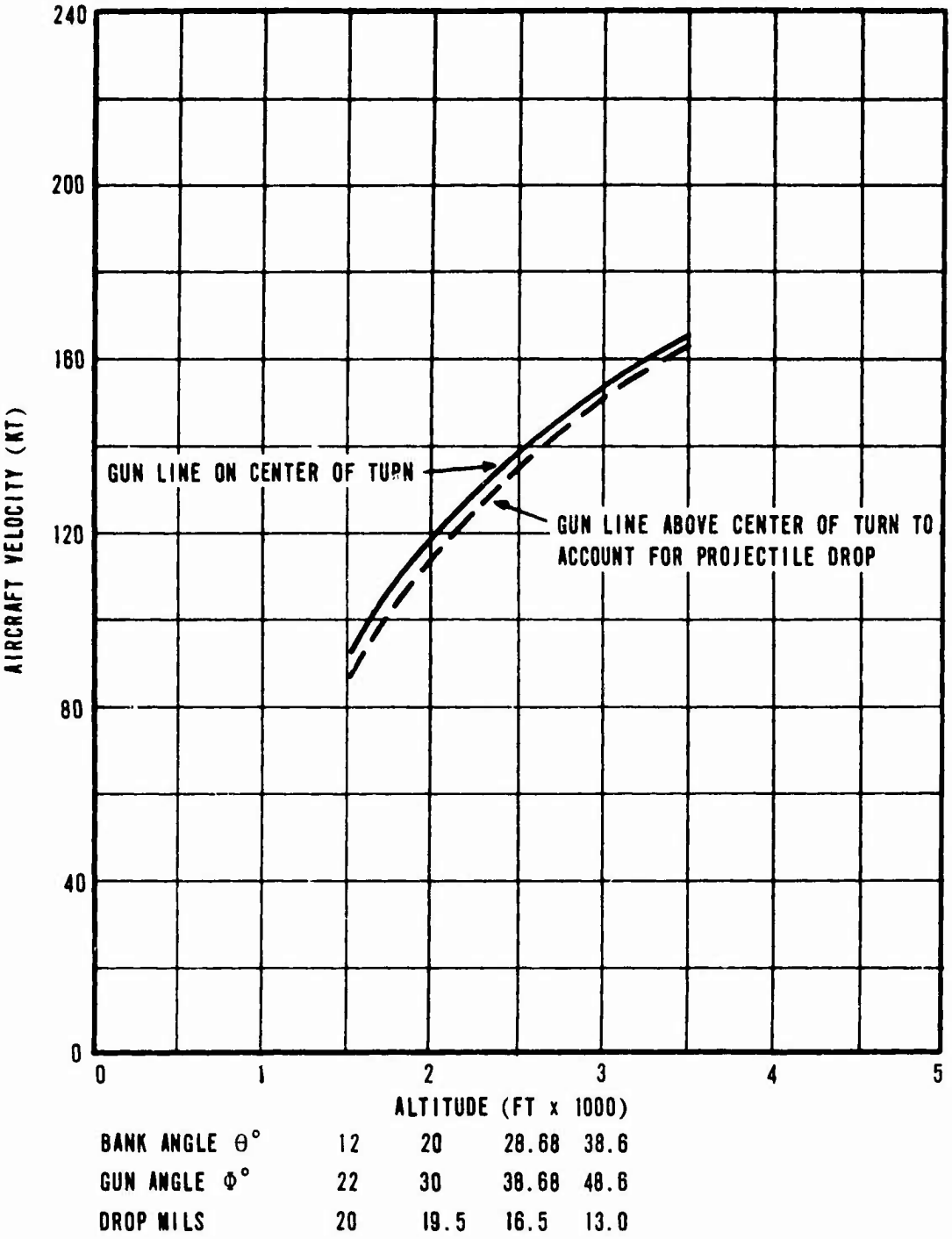
BANK ANGLE $\theta°$	14.5	19.5	24.6	30	35.7	41.7	48.6	56.4
GUN ANGLE $\Phi°$	14.5	19.5	24.6	30	35.7	41.7	48.6	56.4
DROP MILS	47	46	43	41	37	33	28	23

Figure 16. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 0°, Slant Range 6000 Ft.



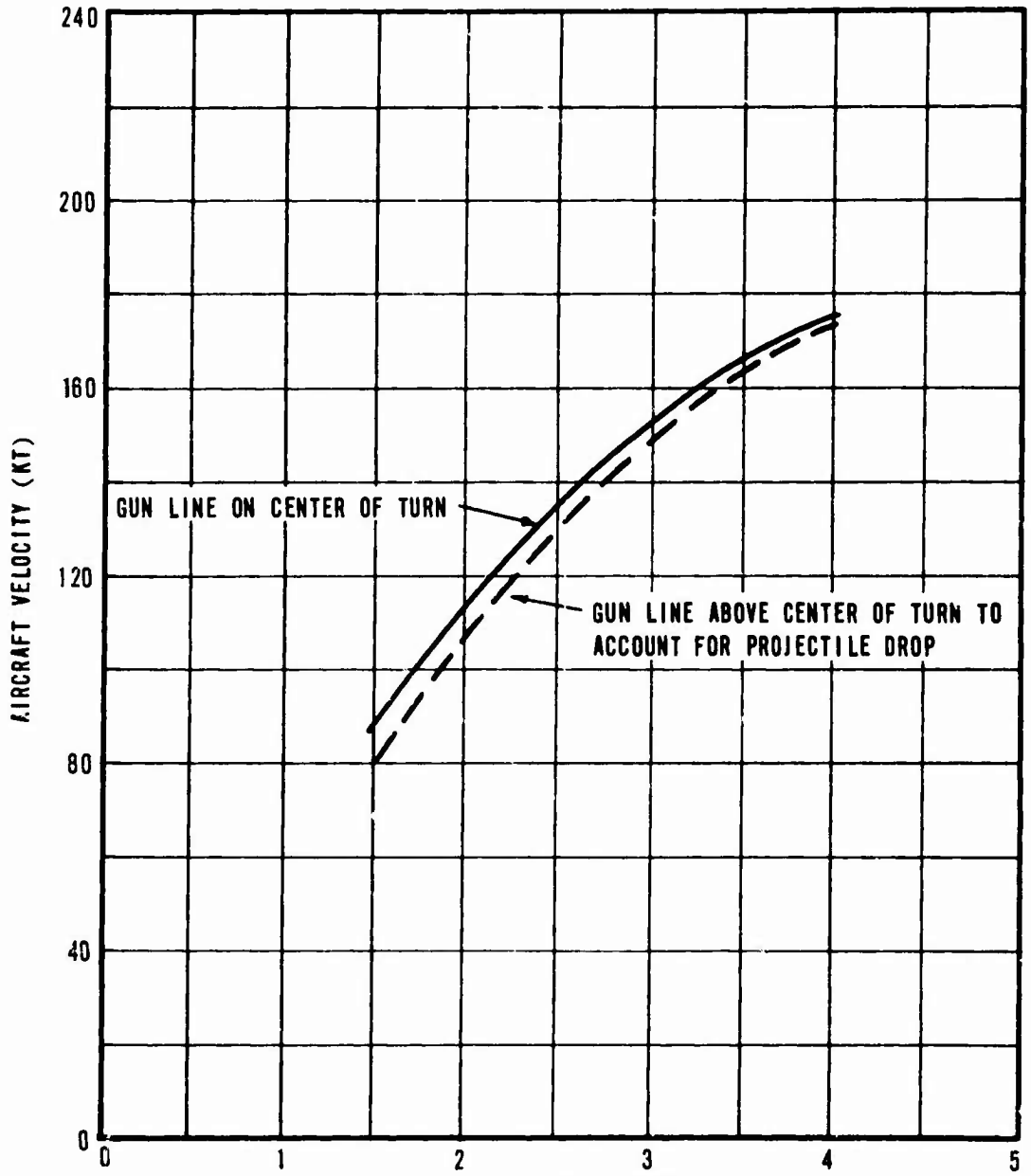
BANK ANGLE θ°	20	31.8	44.4
GUN ANGLE Φ°	30	41.8	54.4
DROP MILS	9.5	8.0	5.0

Figure 17. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 10°, Slant Range 3000 Ft.



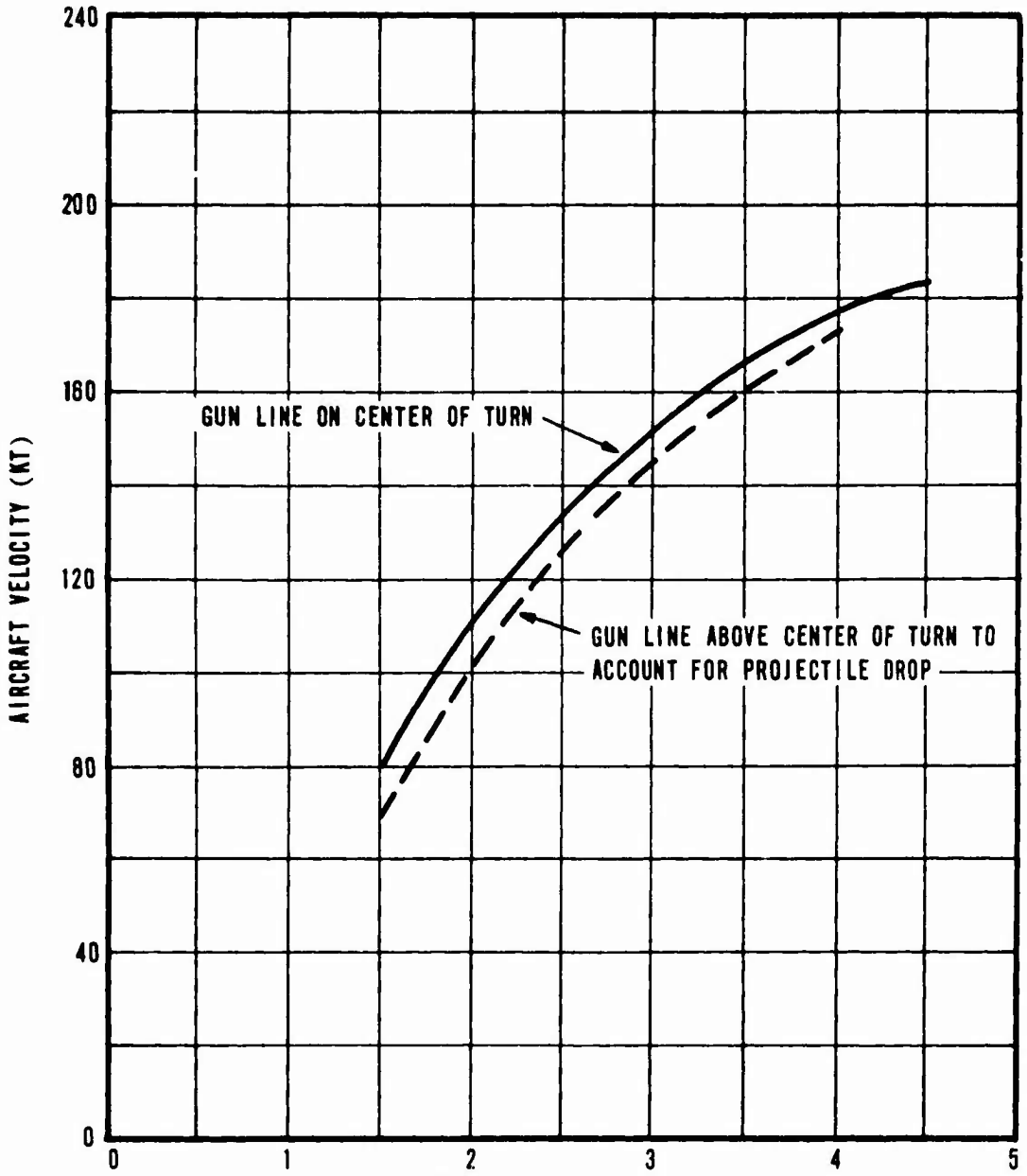
BANK ANGLE θ°	12	20	28.68	38.6
GUN ANGLE Φ°	22	30	38.68	48.6
DROP MILS	20	19.5	16.5	13.0

Figure 18. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 10°, Slant Range 4000 Ft.



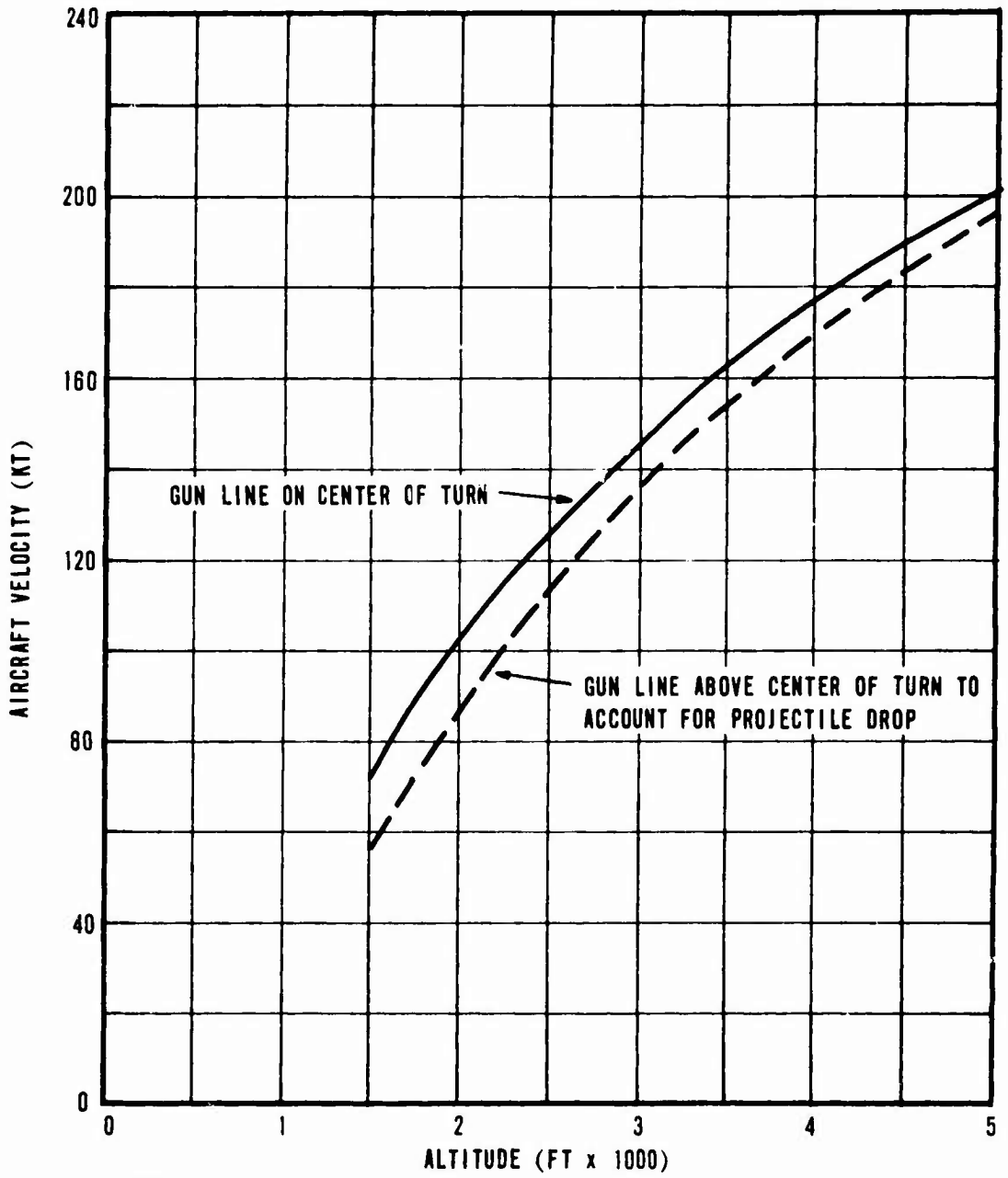
BANK ANGLE θ°	16.4	23.7	31.8	41	52.7
GUN ANGLE Φ°	20.4	23.7	41.8	41	62.7
DROP MILS	27	24	22	12	11

Figure 19. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 10°, Slant Range 4500 Ft.



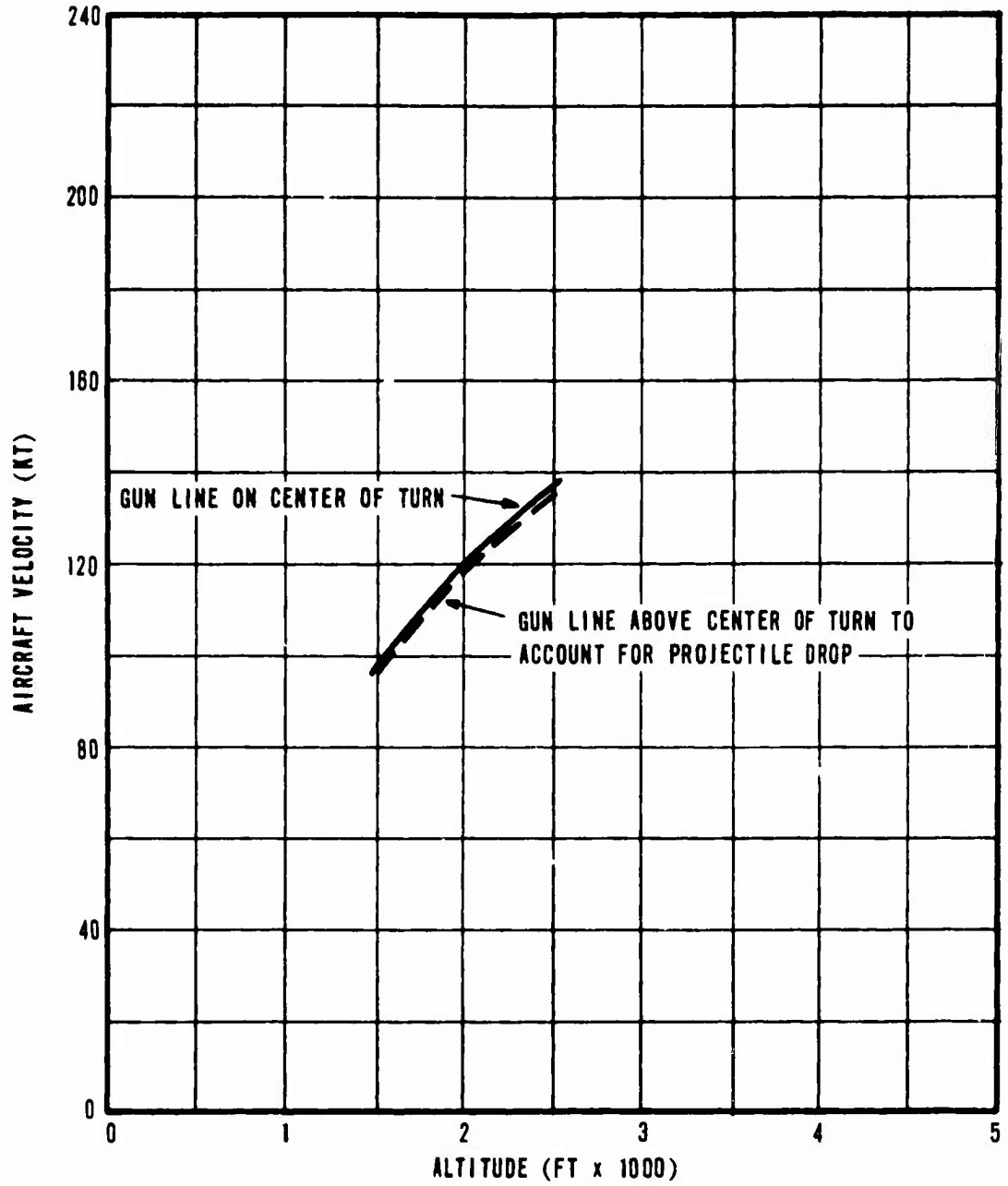
BANK ANGLE $\theta°$	7.5	13.6	20	26.9	34.4	43.1	54.1
GUN ANGLE $\Phi°$	17.5	23.6	30	36.9	44.4	53.1	64.1
DROP MILS	37	35	33	30	25	20	15

Figure 20. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 10°, Slant Range 5000 Ft.



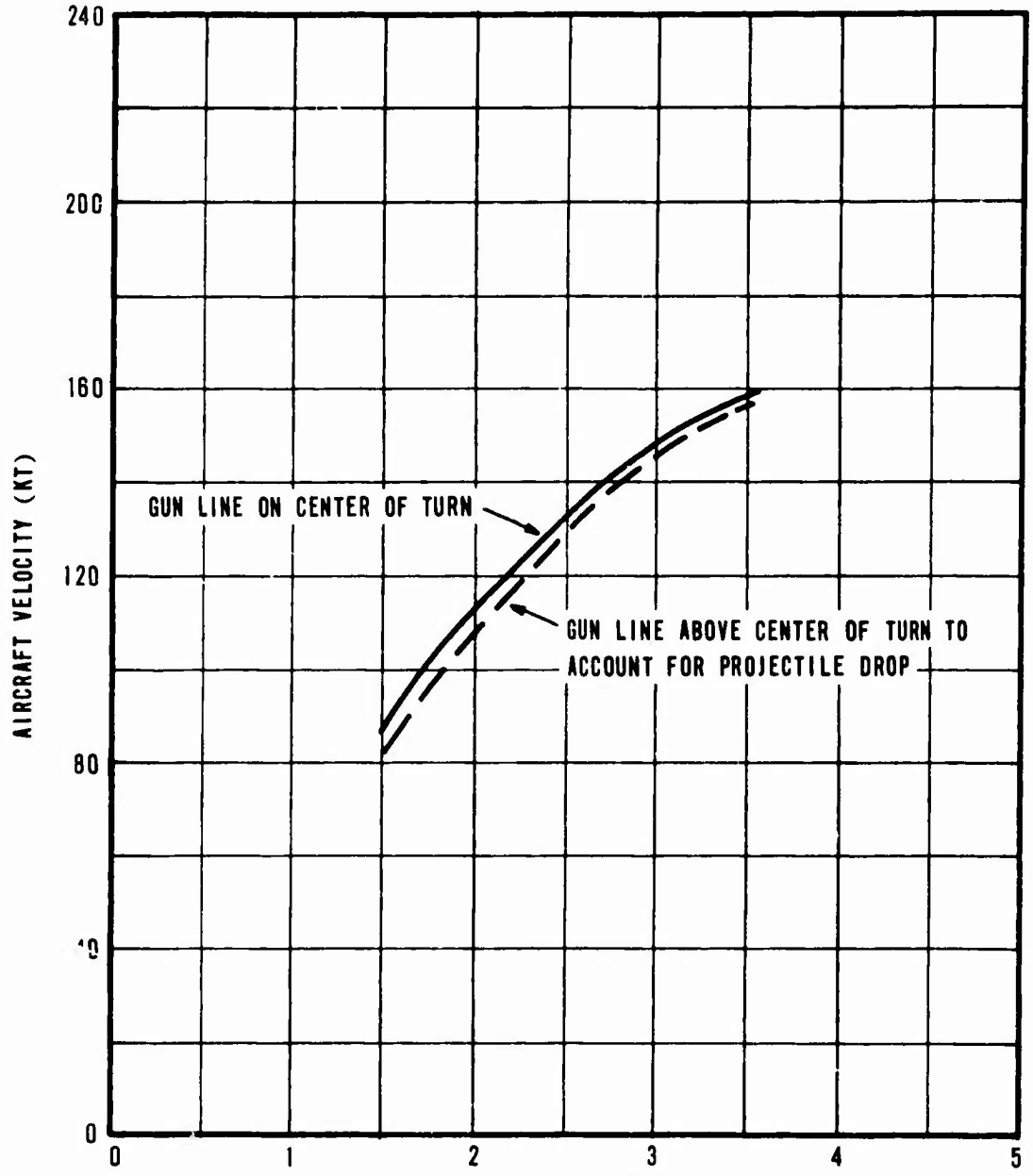
BANK ANGLE θ°	4.5	9.5	14.6	20	25.7	31.8	38.6	46.4
GUN ANGLE Φ°	14.5	19.5	24.6	30	35.7	31.8	48.6	56.4
DROP MILS	47	46	43	41	37	33	28	23

Figure 21. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 10°, Slant Range 6000 Ft.



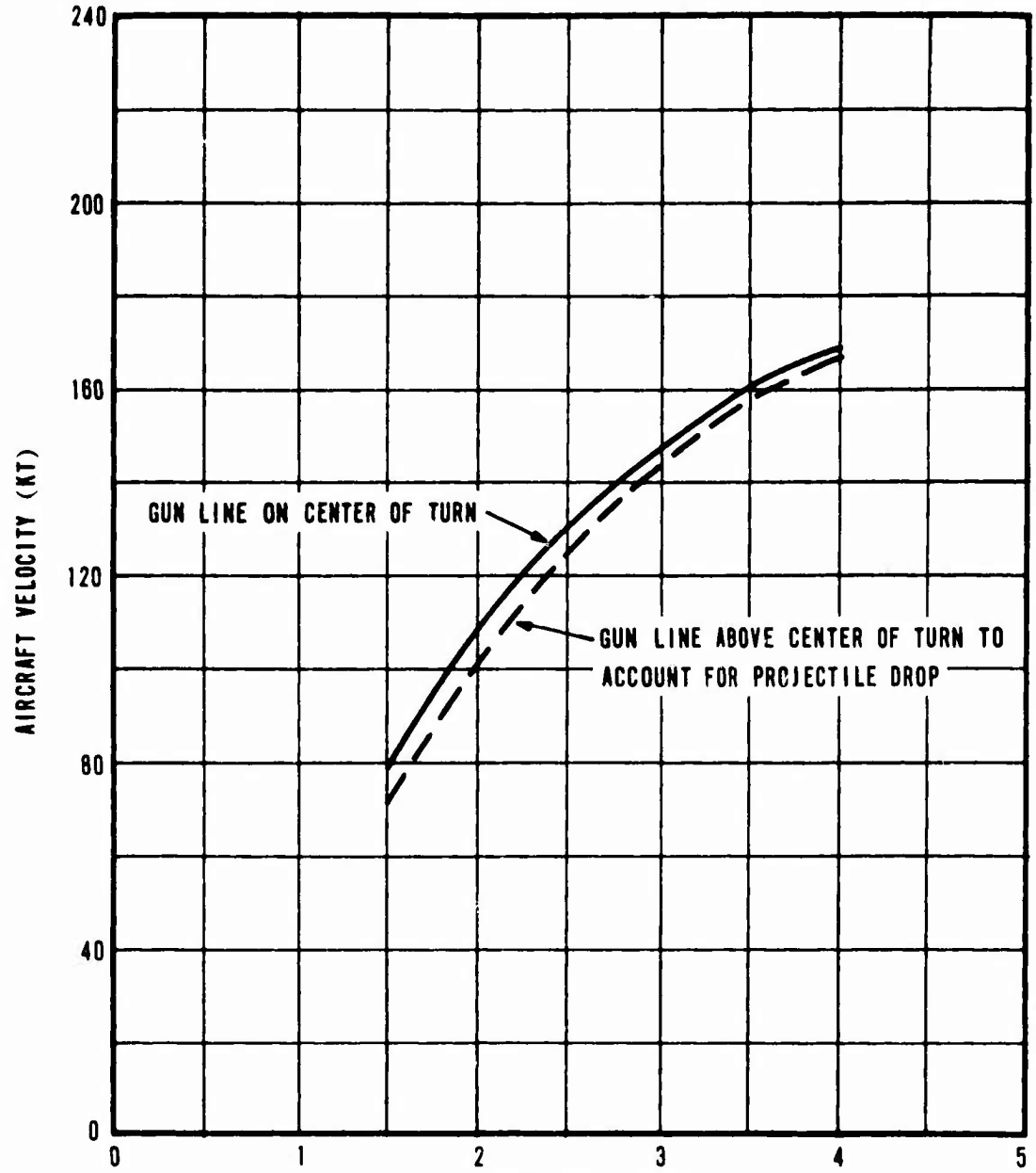
BANK ANGLE θ°	18	29.8	44.4
GUN ANGLE Φ°	30	41.8	56.44
DROP MILS	9.5	8.0	5.0

Figure 22. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 12°, Slant Range 3000 Ft.



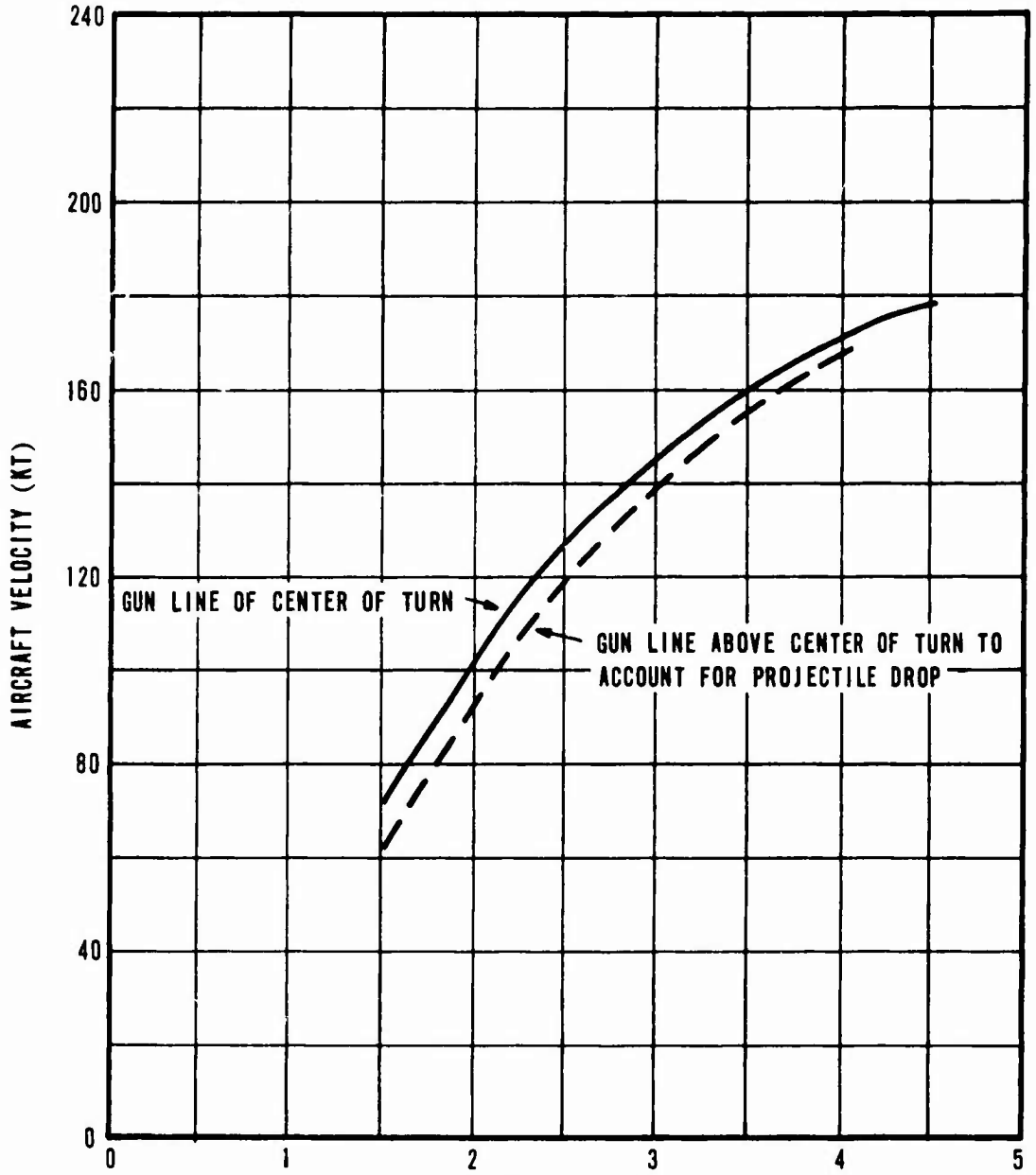
BANK ANGLE $\theta°$	10	18	26.7	36.6	49
GUN ANGLE $\Phi°$	22	30	38.7	48.6	61
DROP MILS	20	19.5	16.5	13	9

Figure 23. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 12°, Slant Range 4000 Ft.



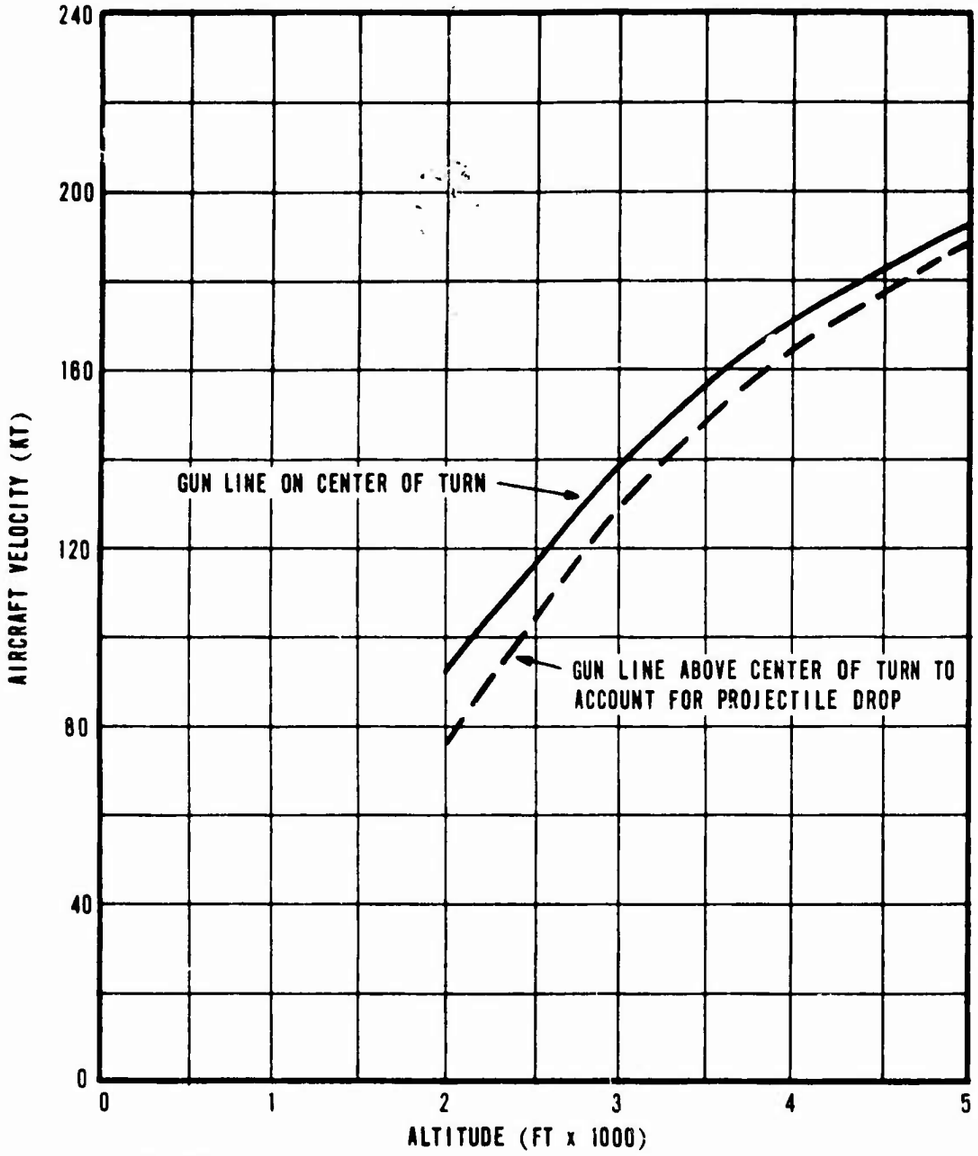
BANK ANGLE θ°	2.5	14.4	21.7	29.8	39	50.7
GUN ANGLE Φ°	19.5	26.4	33.7	41.8	51	62.7
DROP MILS	28	27	24	22	17	11

Figure 24. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 12°, Slant Range 4500 Ft.



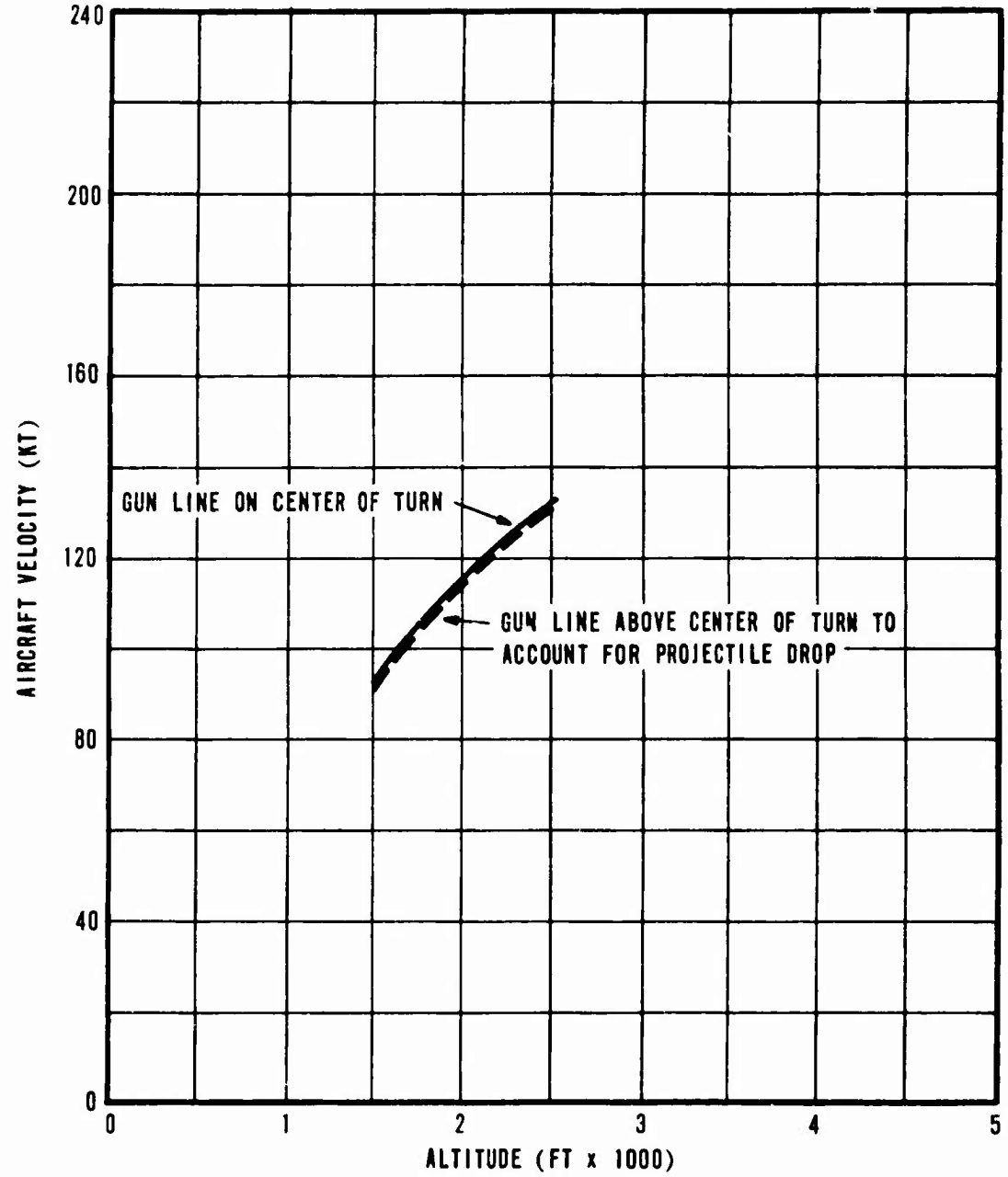
BANK ANGLE $\theta°$	5.5	11.6	18	24.9	32.4	41.1	52.1
GUN ANGLE $\Phi°$	17.5	23.6	30	36.4	44.4	53.1	64.1
DROP MILS	37	35	33	30	25	20	15

Figure 25. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 12°, Slant Range 5000 Ft.



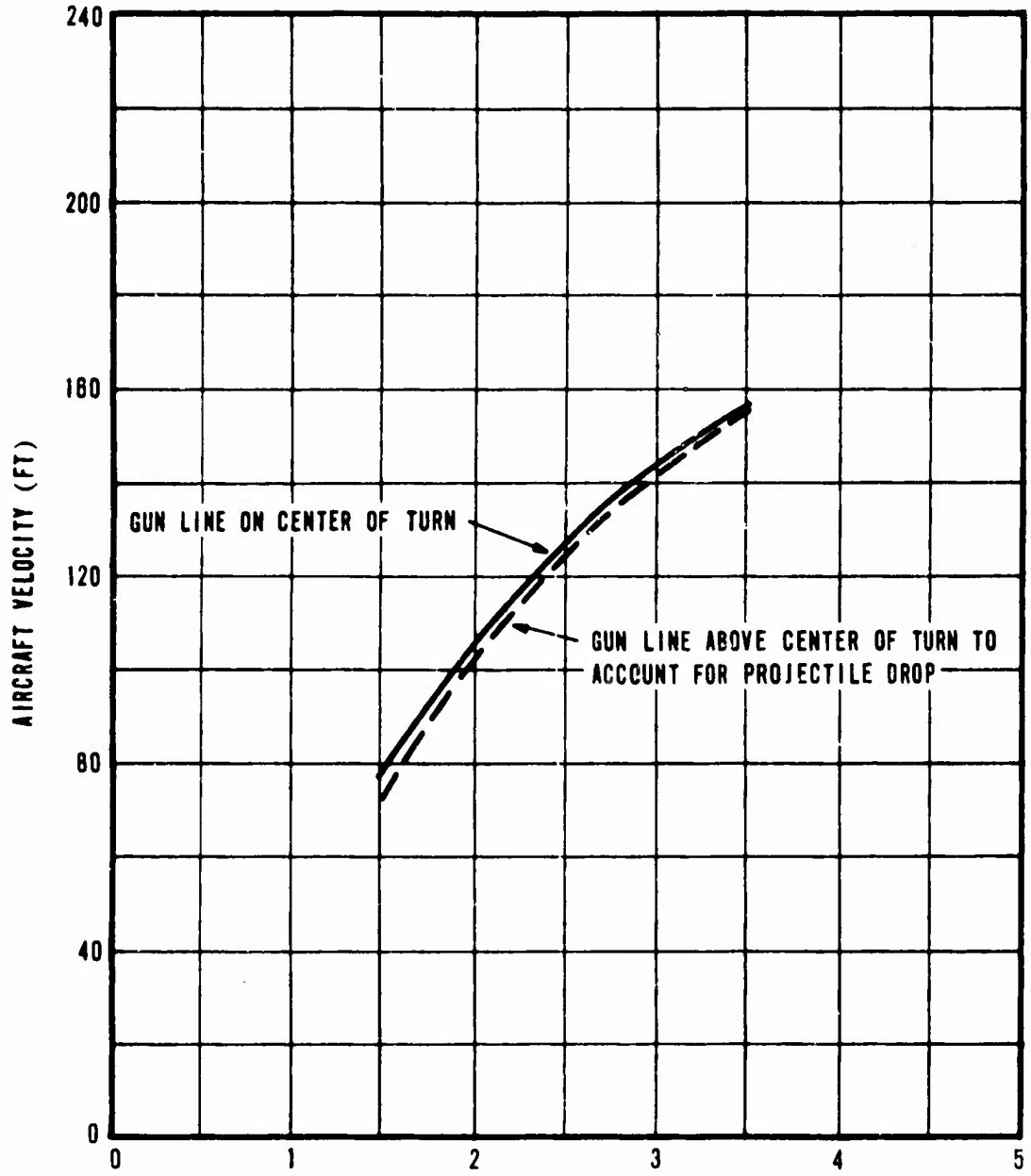
BANK ANGLE θ°	2.5	7.5	12.6	18	23.7	29.7	36.6	44.8
GUN ANGLE Φ°	11.5	19.5	24.6	30	35.7	41.7	48.6	56.4
DROP MILS	47	46	43	41	37	33	28	23

Figure 26. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn, Gun Declination 12°, Slant Range 6000 Ft.



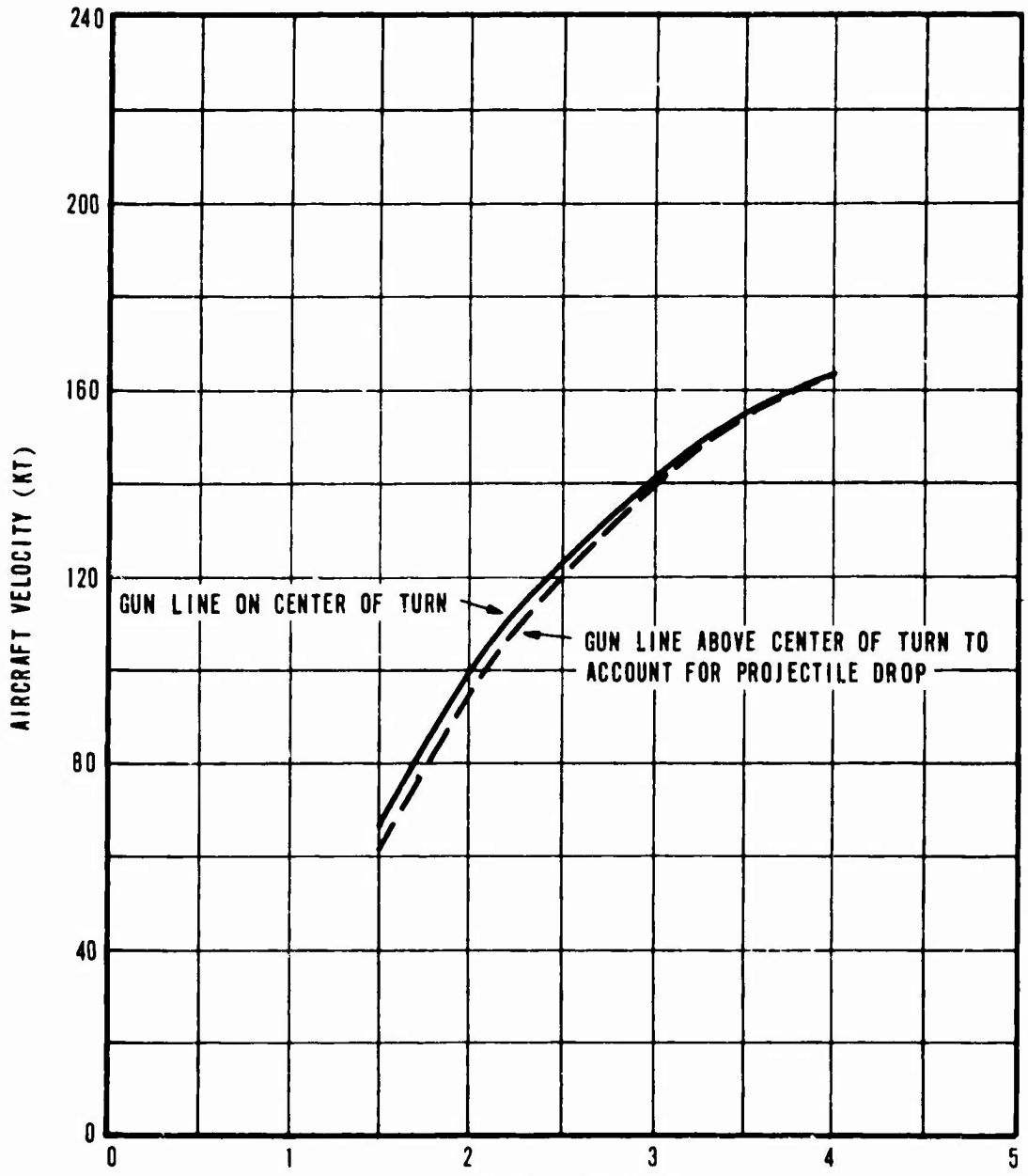
BANK ANGLE $\theta°$	16	27.8	42.4
GUN ANGLE $\Phi°$	30	41.8	56.4
DROP MILS	10.5	8.5	8.0

Figure 27. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 14°, Slant Range 3000 Ft.



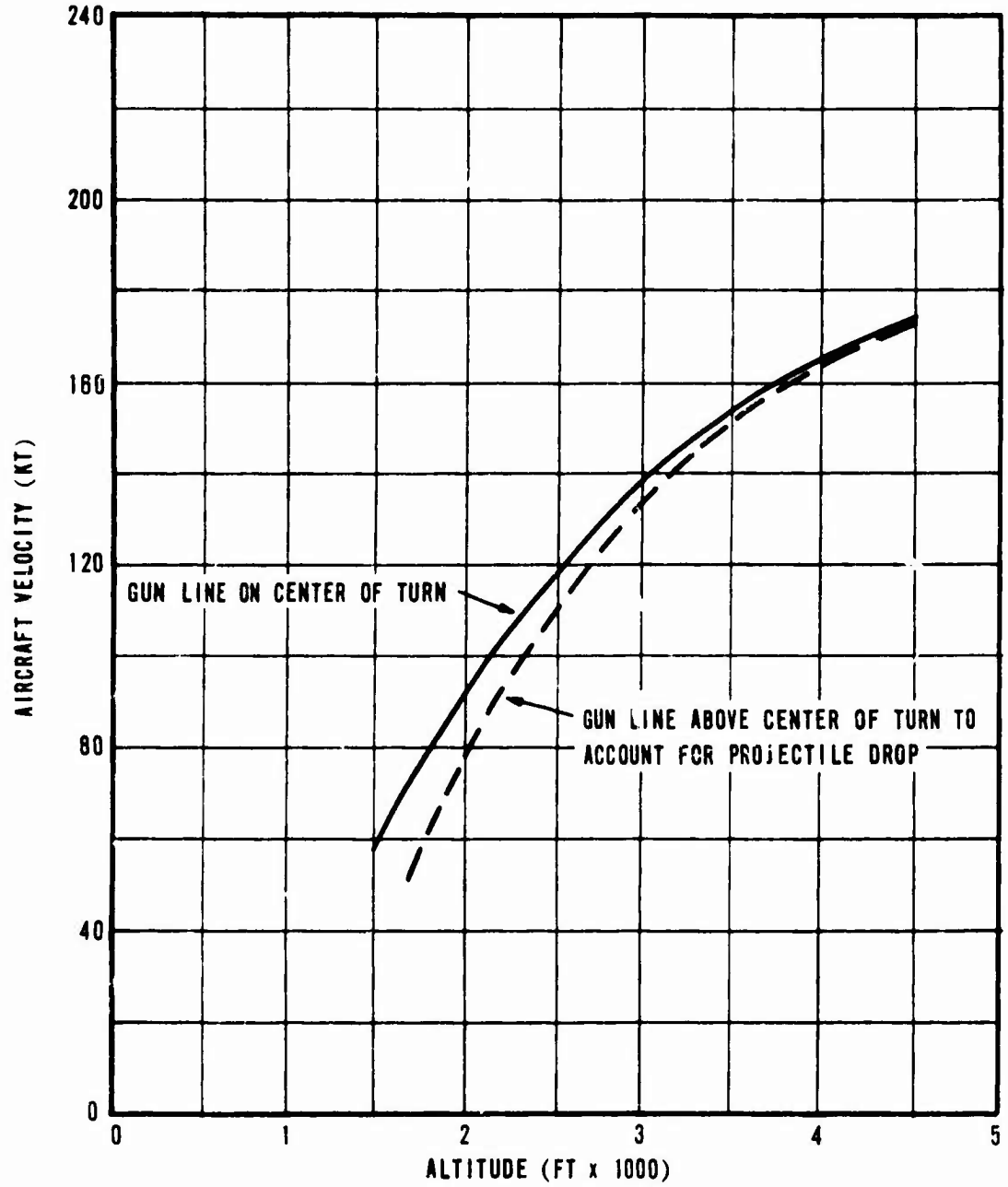
BANK ANGLE θ°	8.0	16.0	24.7	34.6	47.0
GUN ANGLE Φ°	22.0	30.0	38.7	48.6	61.04
DROP MILS	20	19.4	17.5	13.0	9.0

Figure 28. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 14°, Slant Range 4000 Ft.



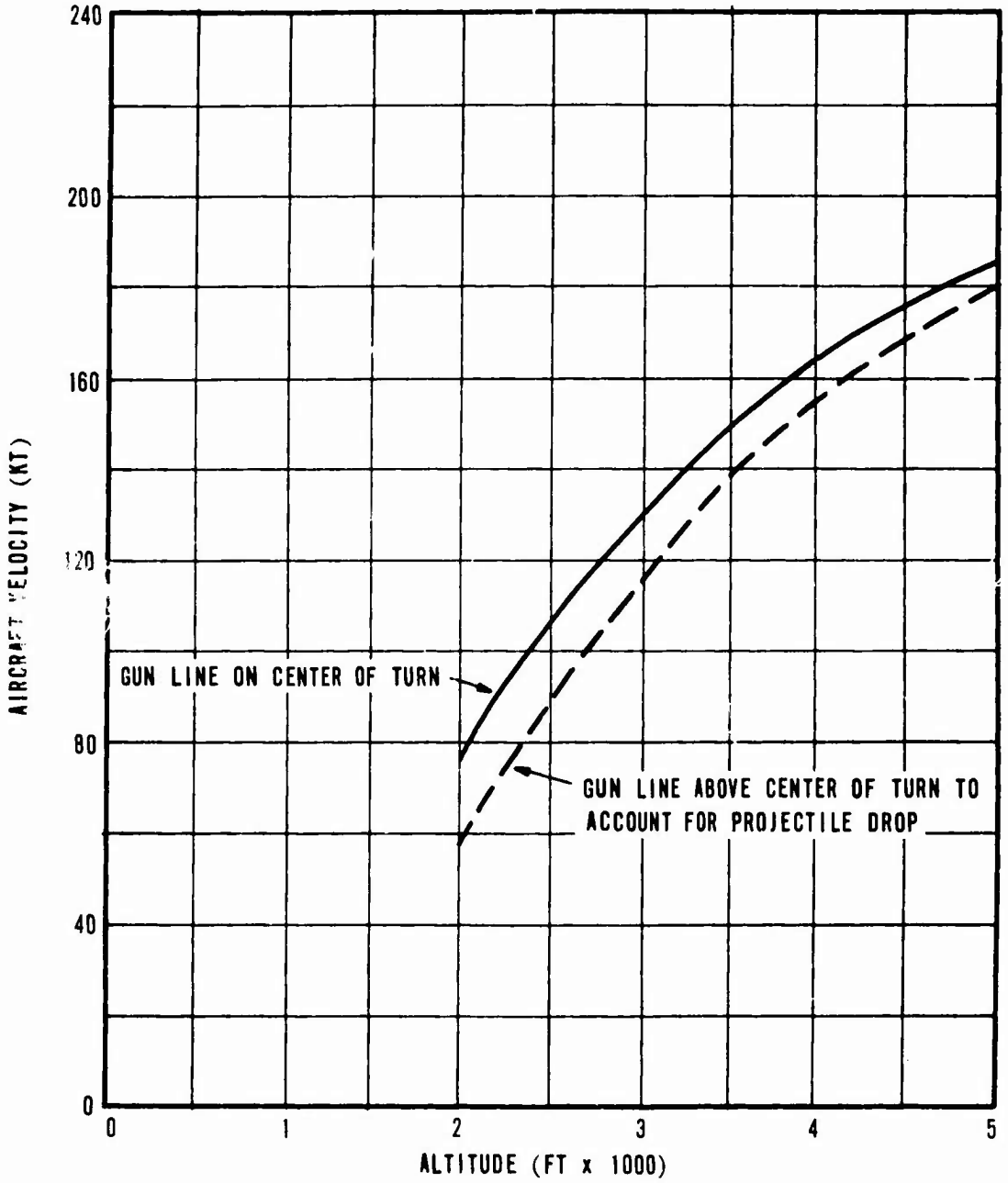
BANK ANGLE θ°	5.5	12.4	19.7	27.8	37.0	48.7
GUN ANGLE Φ°	19.5	26.4	33.7	41.8	51.0	62.7
DROP MILS	27	26.5	24	22	16	12

Figure 29. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 14°, Slant Range 4500 Ft.



BANK ANGLE θ°	3.5	9.6	16	22.9	30.4	39.1	50.1
GUN ANGLE Φ°	17.5	23.6	30	36.9	44.4	53.1	64.1
DROP MILS	37	35	32.7	30	25	22	15

Figure 30. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn, Gun Declination 14°, Slant Range 5000 Ft.



BANK ANGLE θ°	5.5	10.6	16	21.7	28.1	34.6	42.4
GUN ANGLE Φ°	9.5	24.6	30	35.7	42.2	48.6	56.4
DROP MILS	57	52	50	44	39.5	35	31

Figure 31. True Airspeed Necessary to Have Gun Line and Sight Line on Center of Turn. Gun Declination 14°, Slant Range 6000 Ft.

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CURVE SET IV

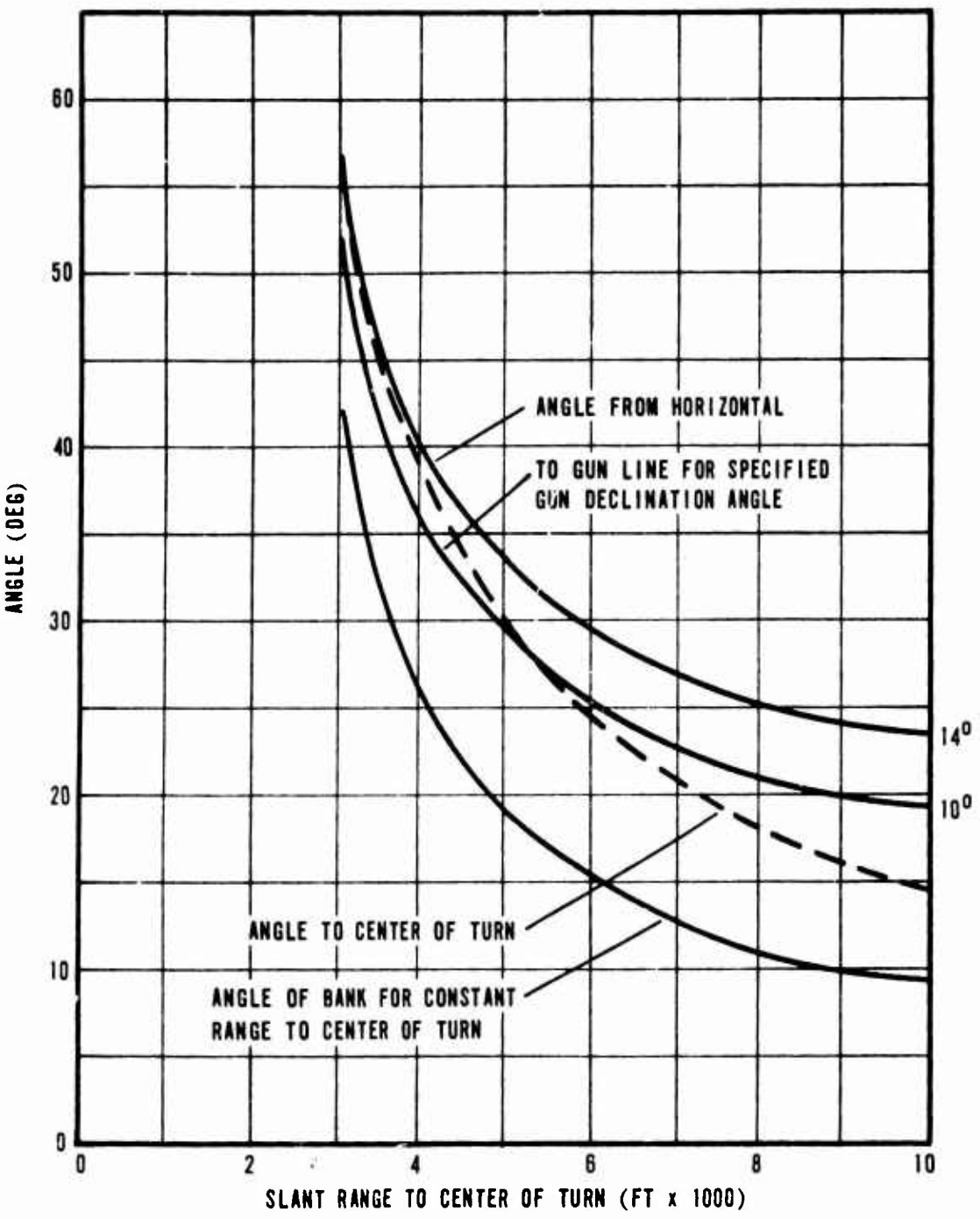

Figure 32. Angle of Bank for Constant Slant Range, Altitude 2500 Ft, Airspeed 130 Kt.

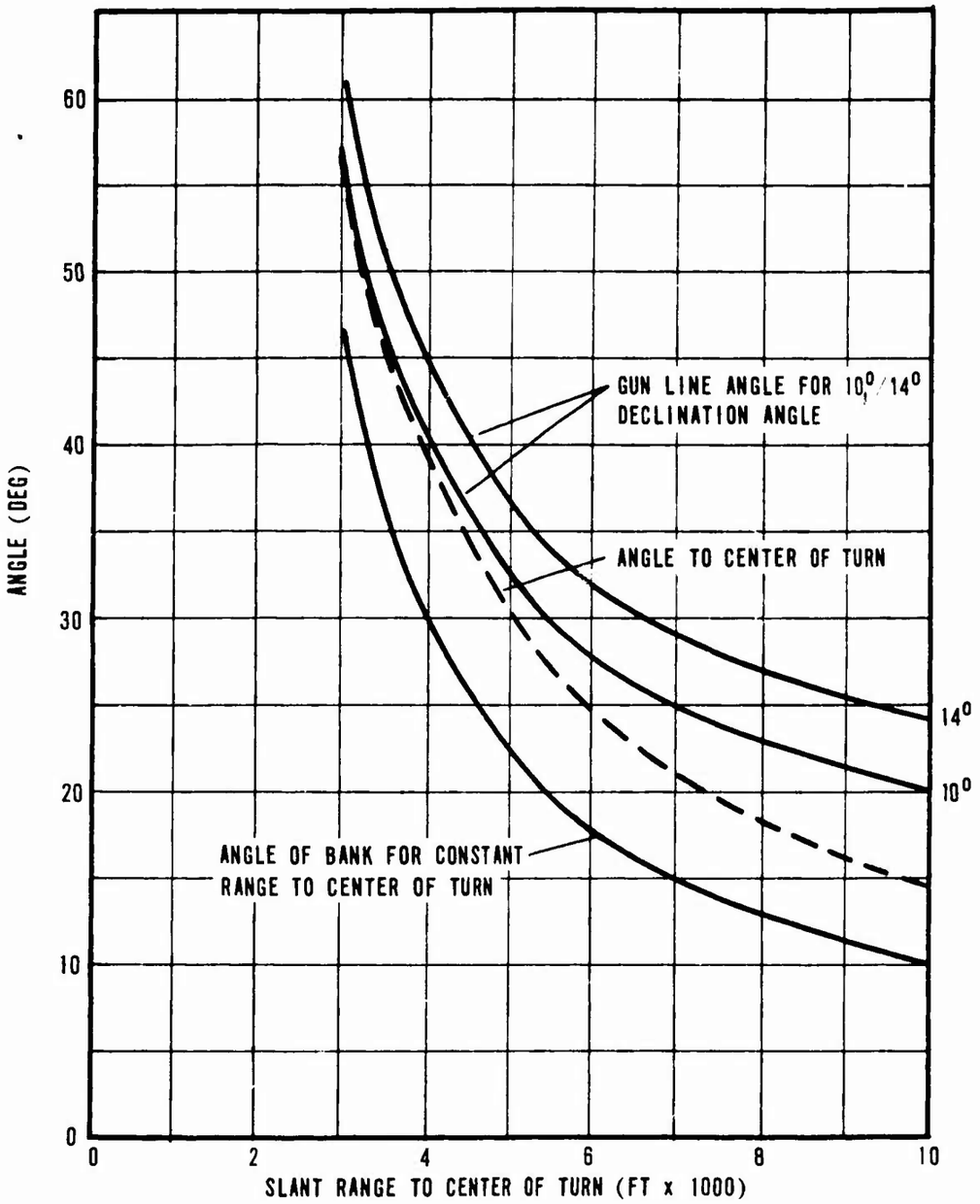

Figure 33. Angle of Bank for Constant Slant Range, Altitude 2500 Ft, Airspeed 140 Kt.

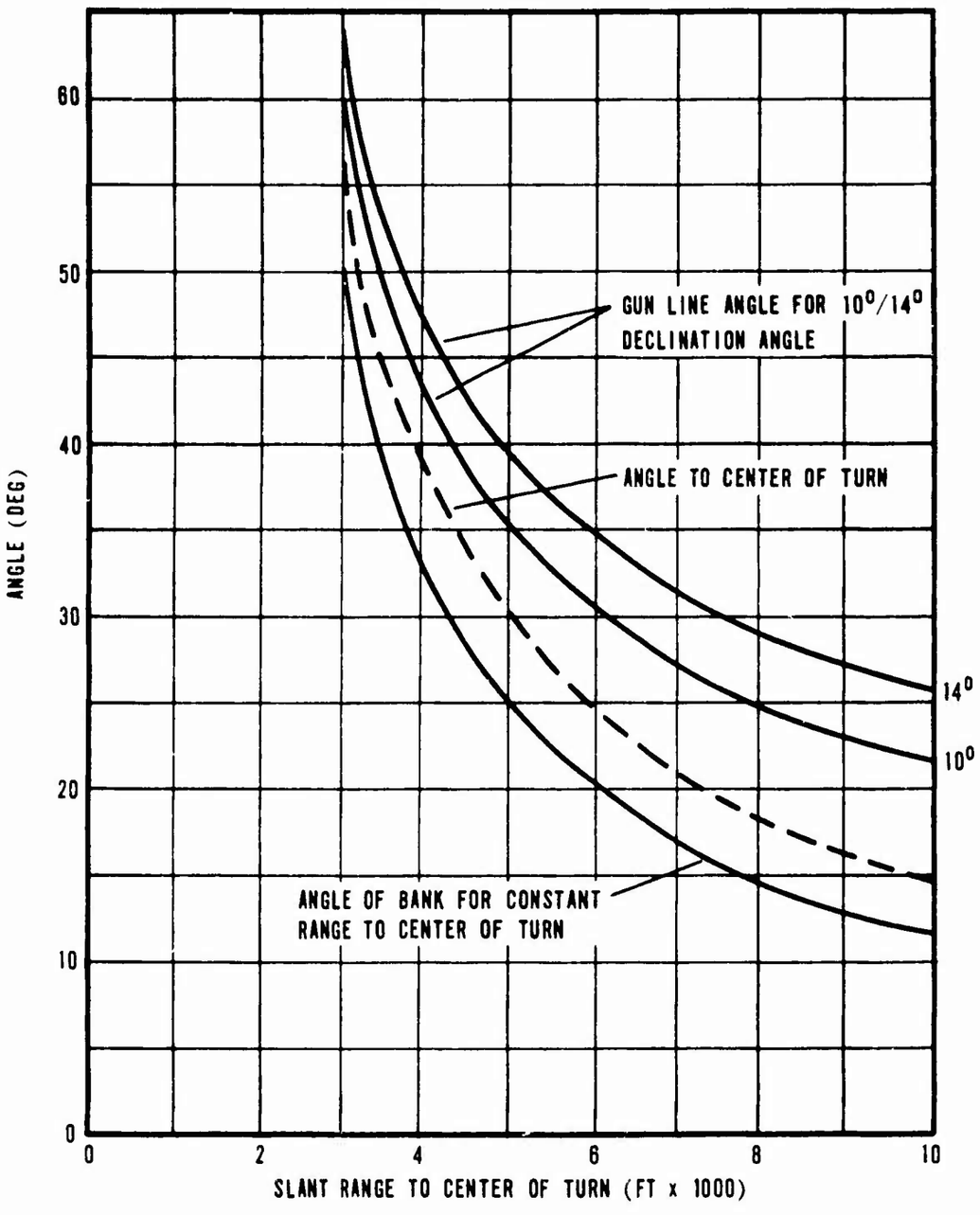

Figure 34. Angle of Bank for Constant Slant Range, Altitude 2500 Ft, Airspeed 150 Kt.

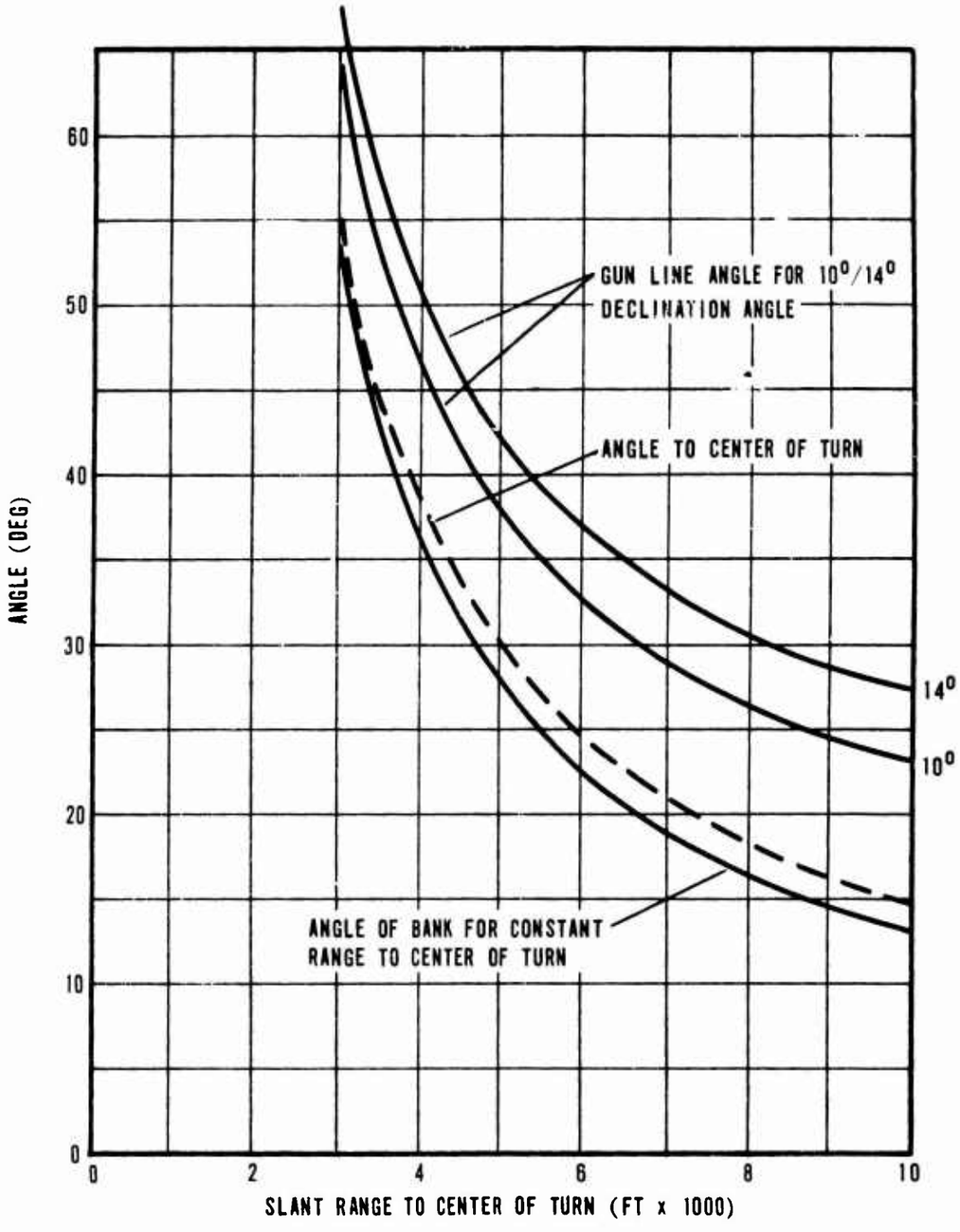

Figure 35. Angle of Bank for Constant Slant Range, Altitude 2500 Ft, Airspeed 160 Kt.

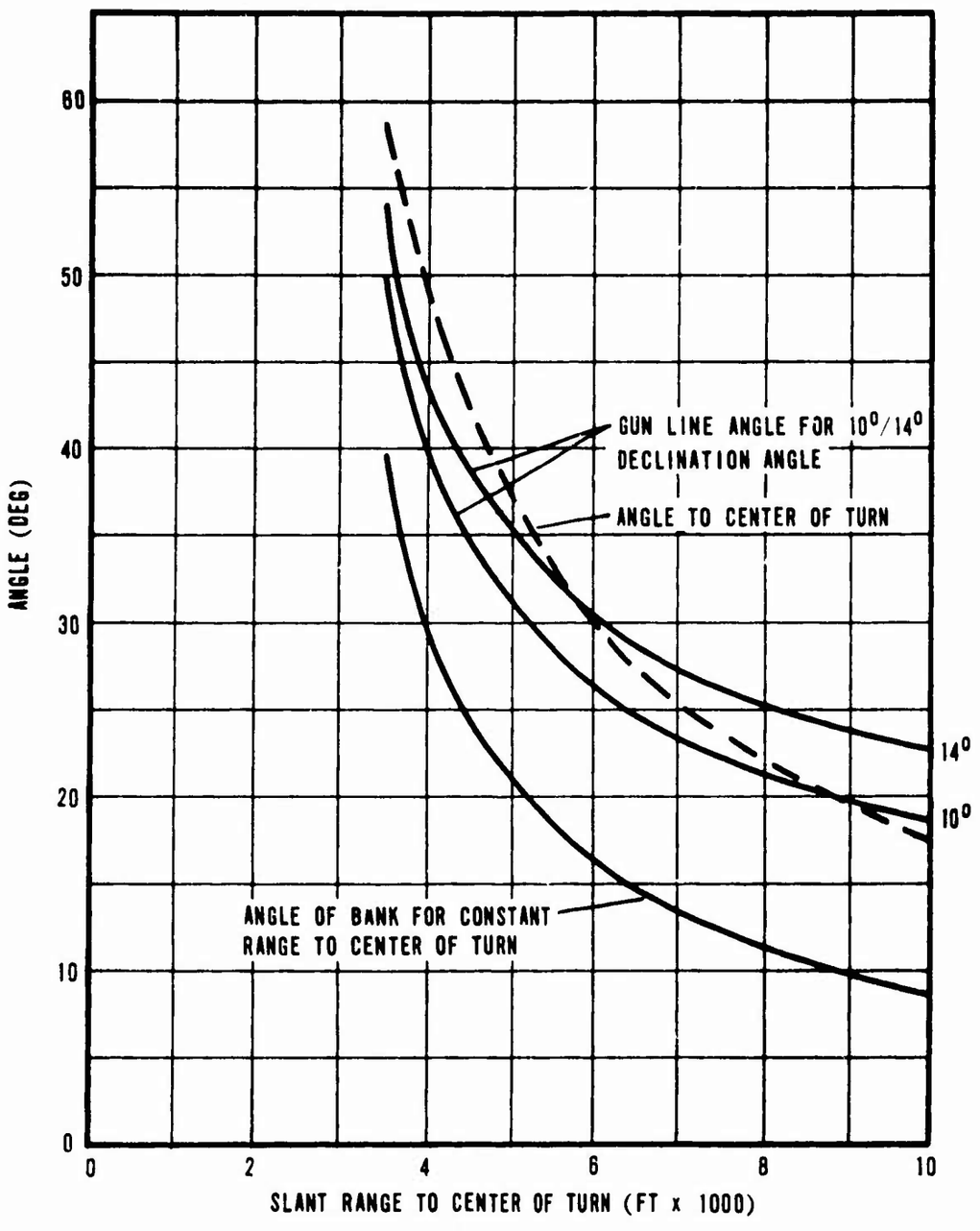

Figure 36. Angle of Bank for Constant Slant Range, Altitude 3000 Ft, Airspeed 130 Kt.

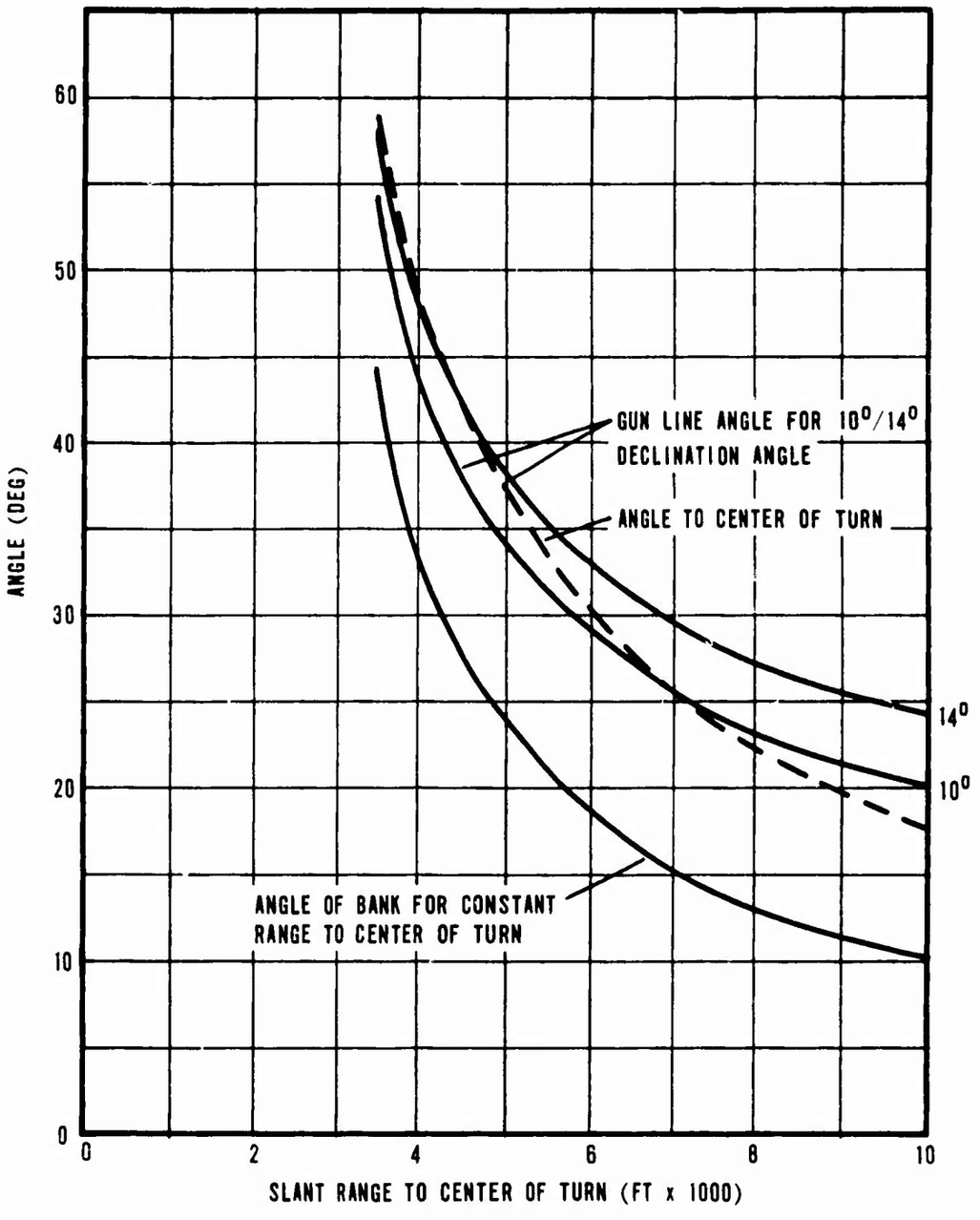

Figure 37. Angle of Bank for Constant Slant Range, Altitude 3000 Ft, Airspeed 140 Kt.

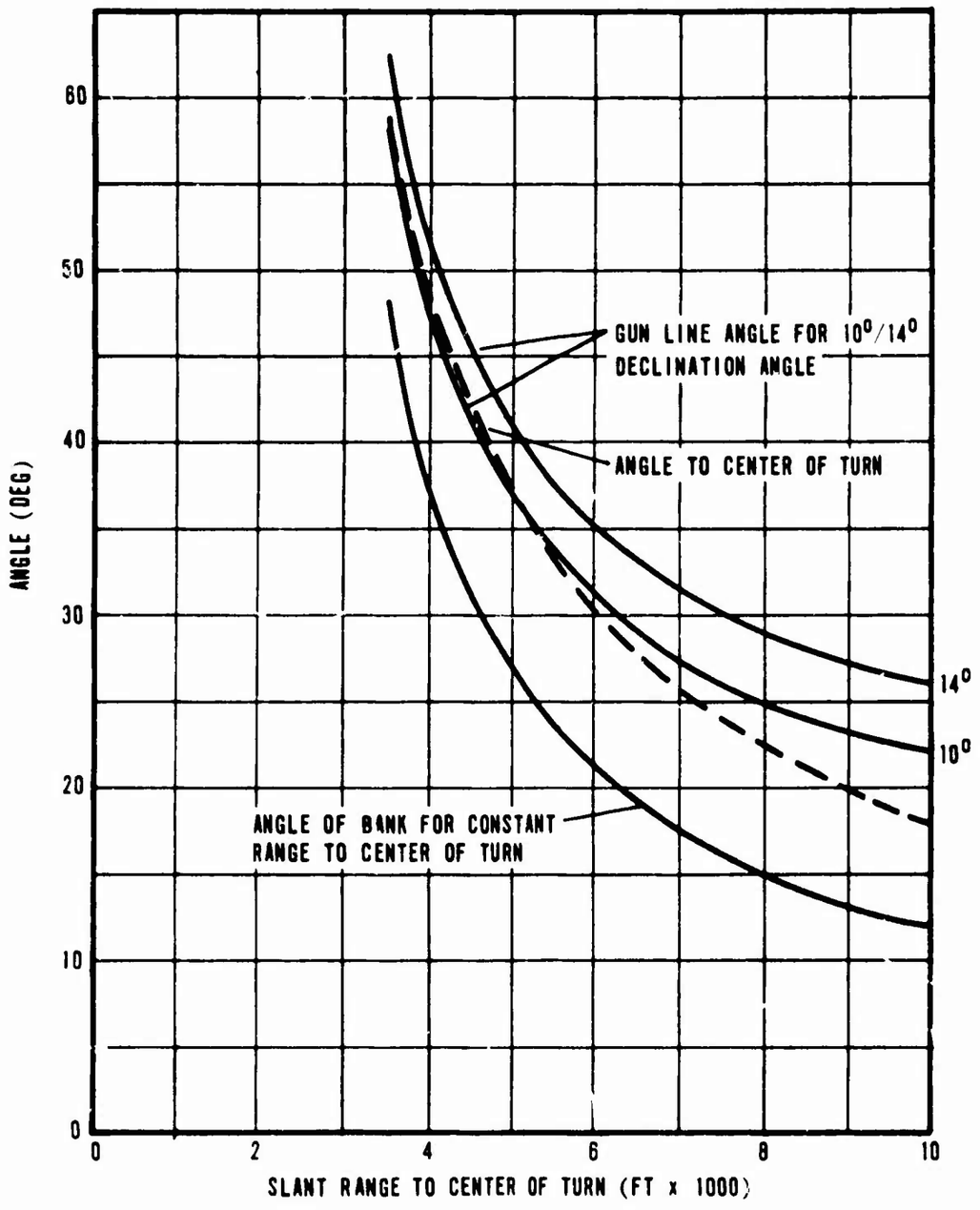

Figure 38. Angle of Bank for Constant Slant Range, Altitude 3000 Ft, Airspeed 150 Kt.

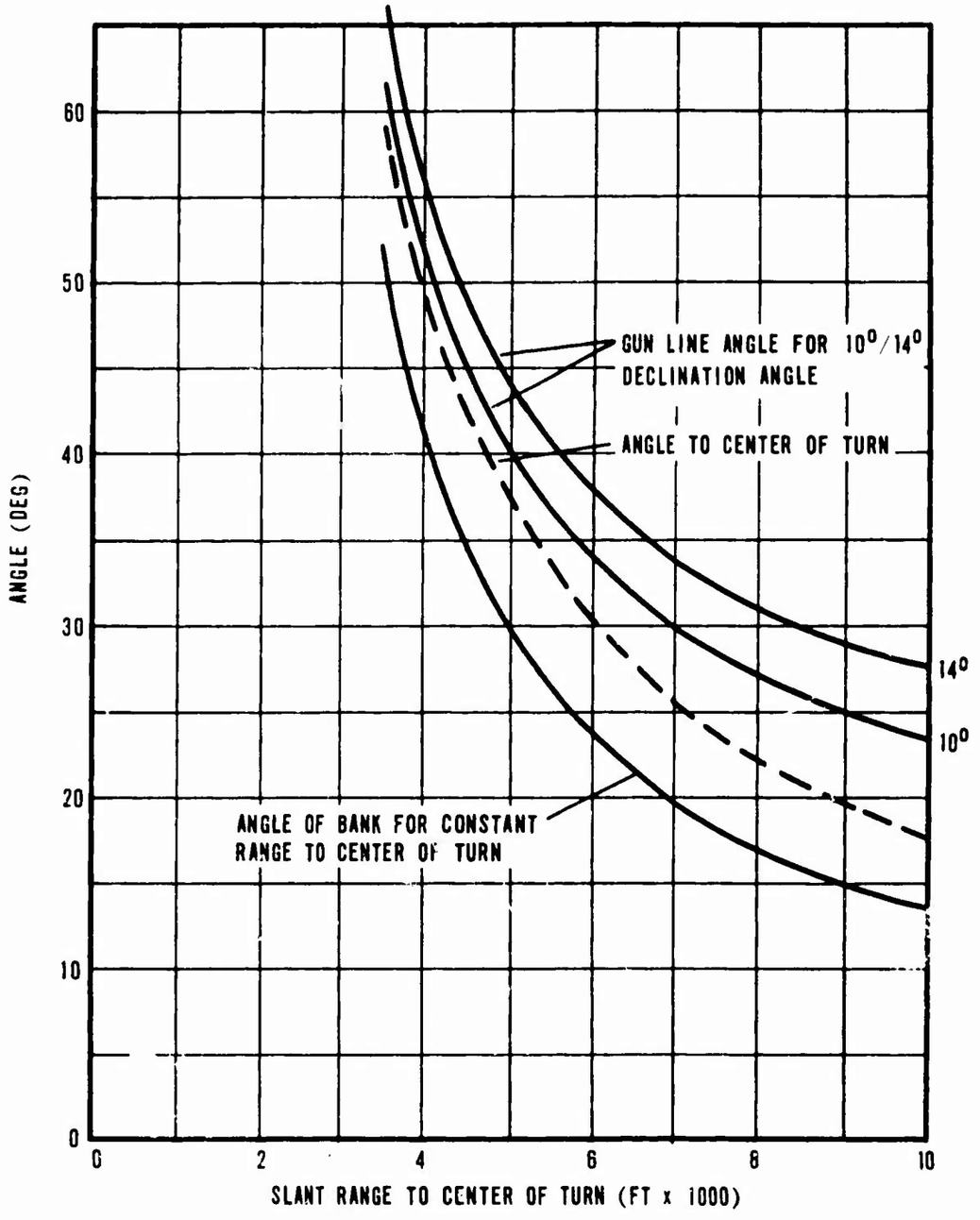

Figure 39. Angle of Bank for Constant Slant Range, Altitude 3000 Ft, Airspeed 160 Kt.

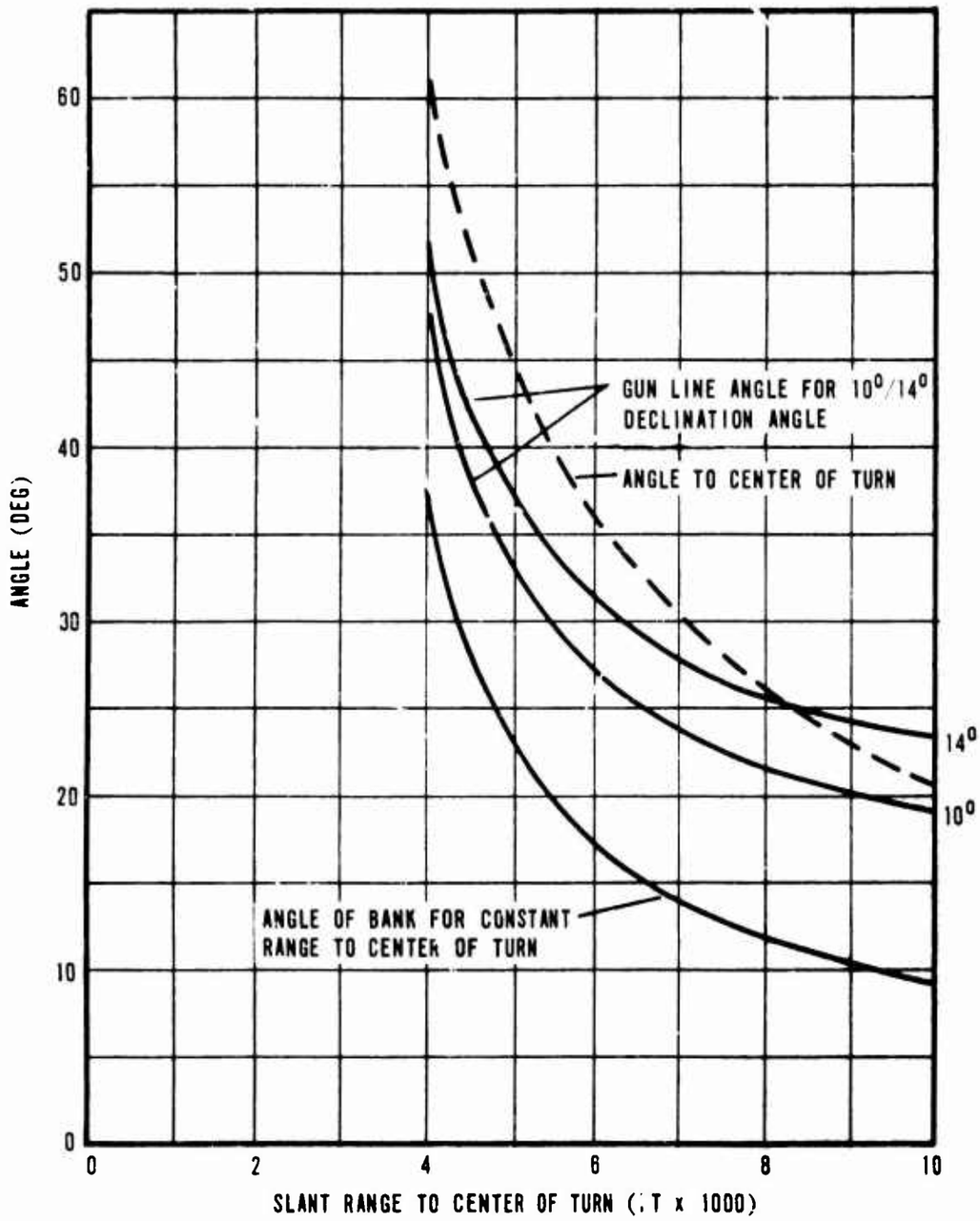

Figure 40. Angle of Bank for Constant Slant Range, Altitude 3500 Ft, Airspeed 130 Kt.

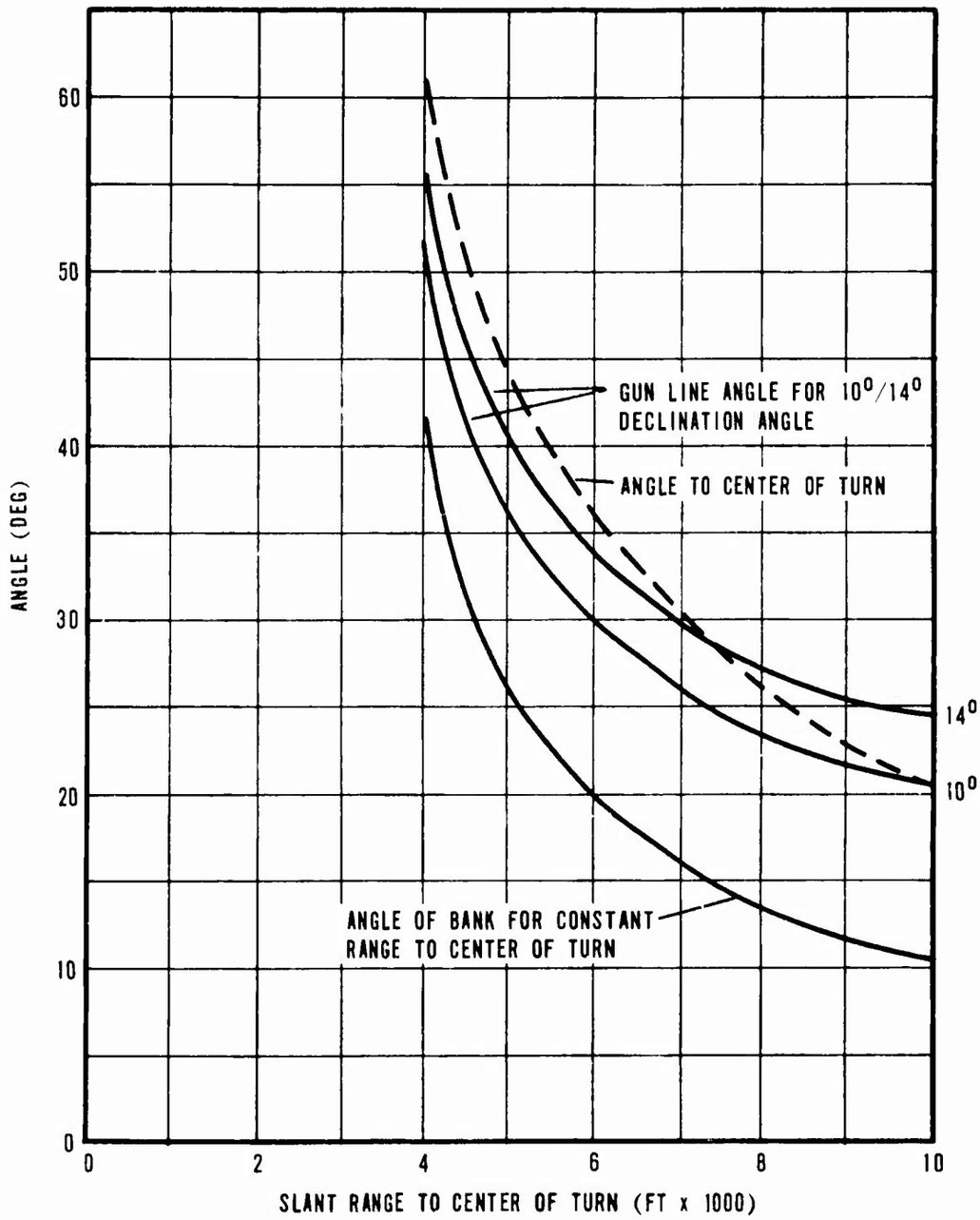

Figure 41. Angle of Bank for Constant Slant Range, Altitude 3500 Ft, Airspeed 140 Kt.

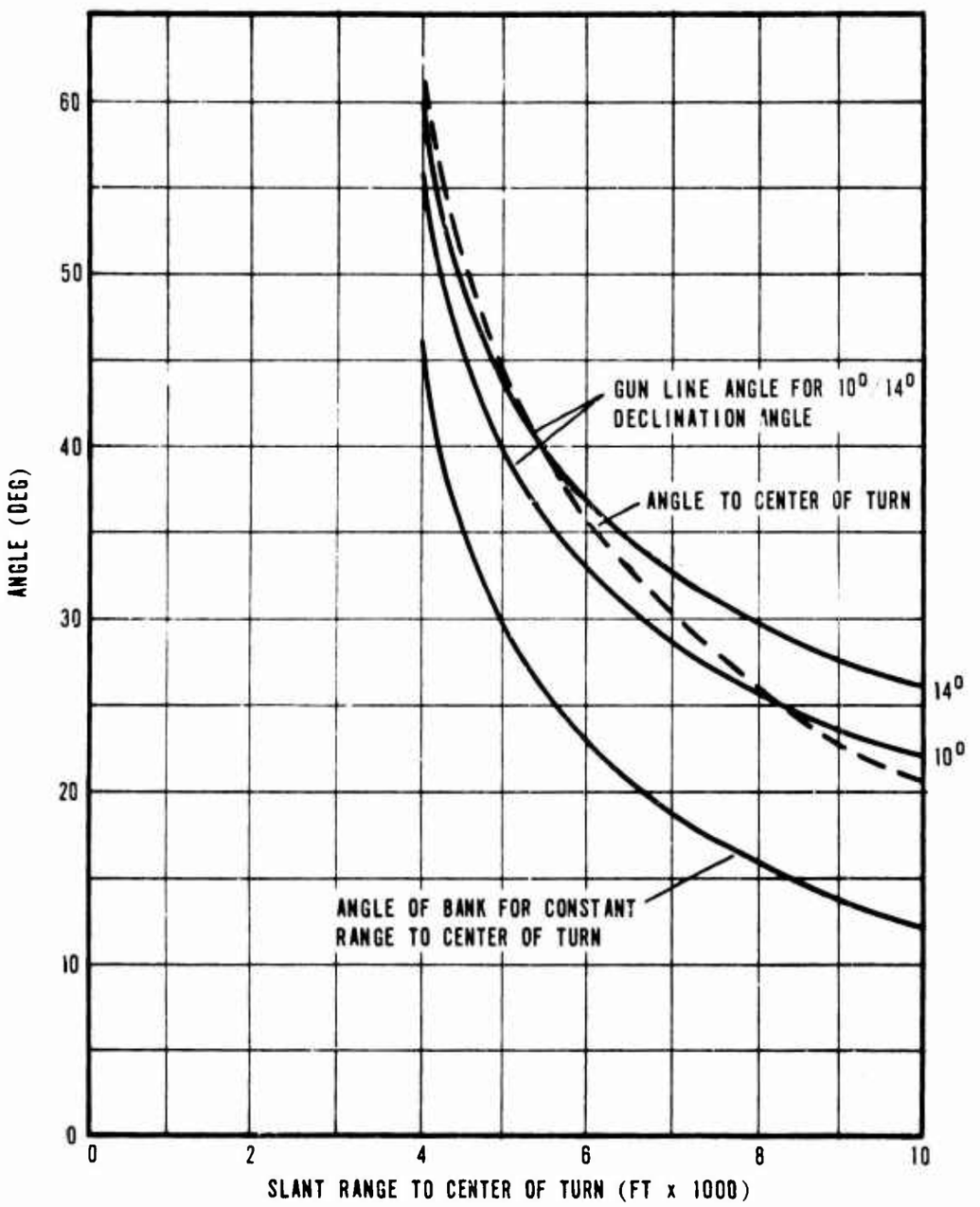

Figure 42. Angle of Bank for Constant Slant Range, Altitude 3500 Ft, Airspeed 150 Kt.

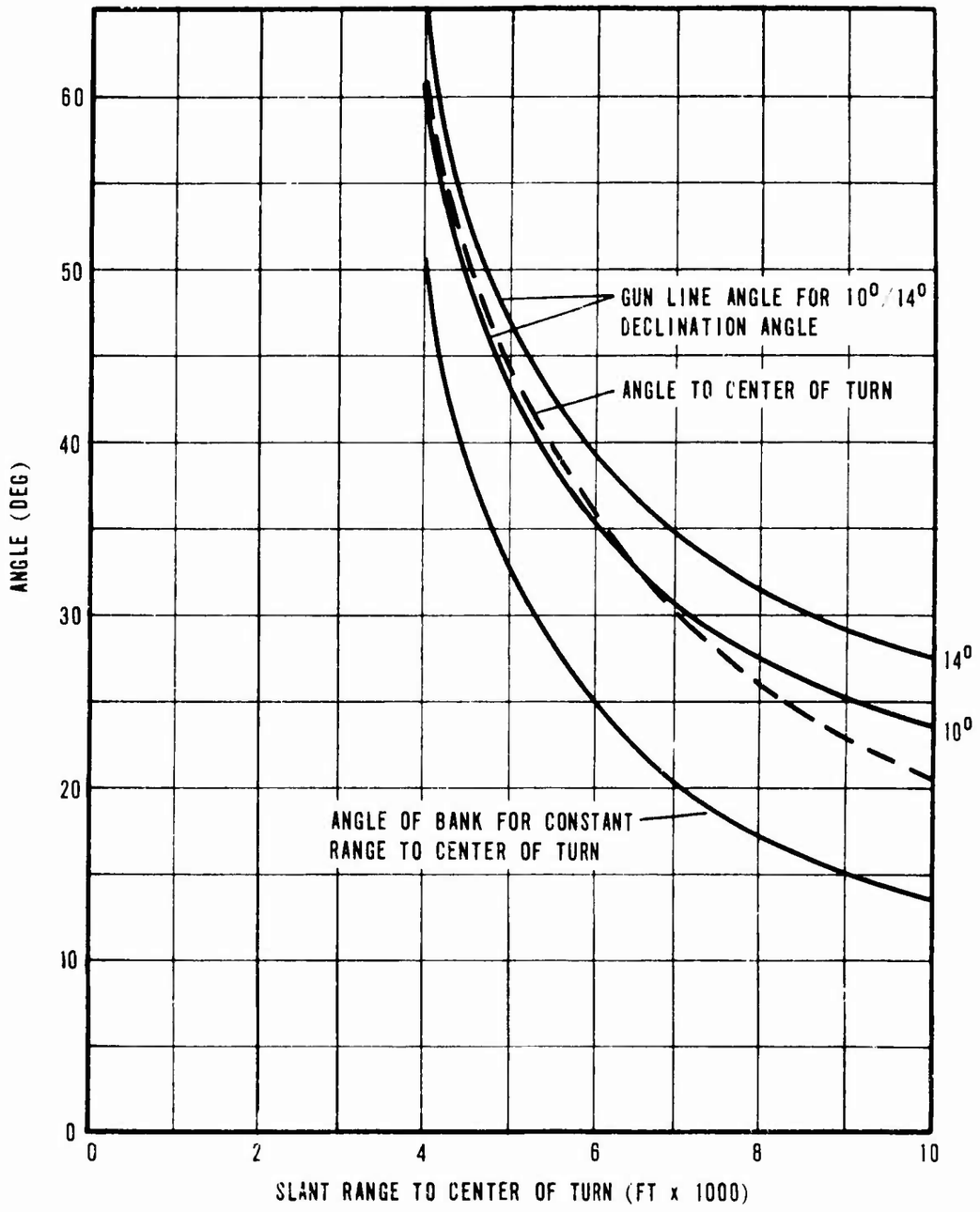

Figure 43. Angle of Bank for Constant Slant Range, Altitude 3500 Ft, Airspeed 160 Kt.

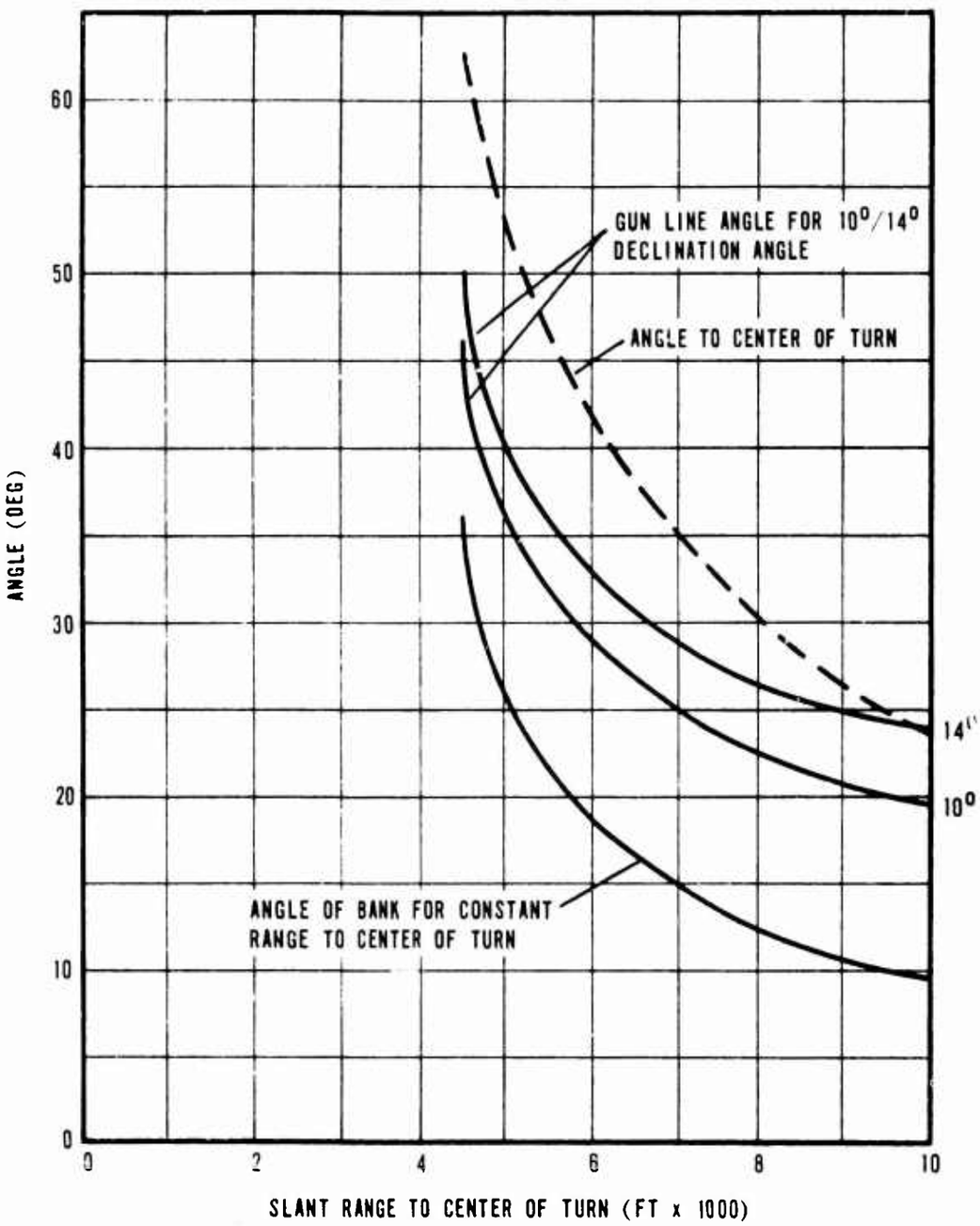

Figure 44. Angle of Bank for Constant Slant Range, Altitude 4000 Ft, Airspeed 150 Kt.

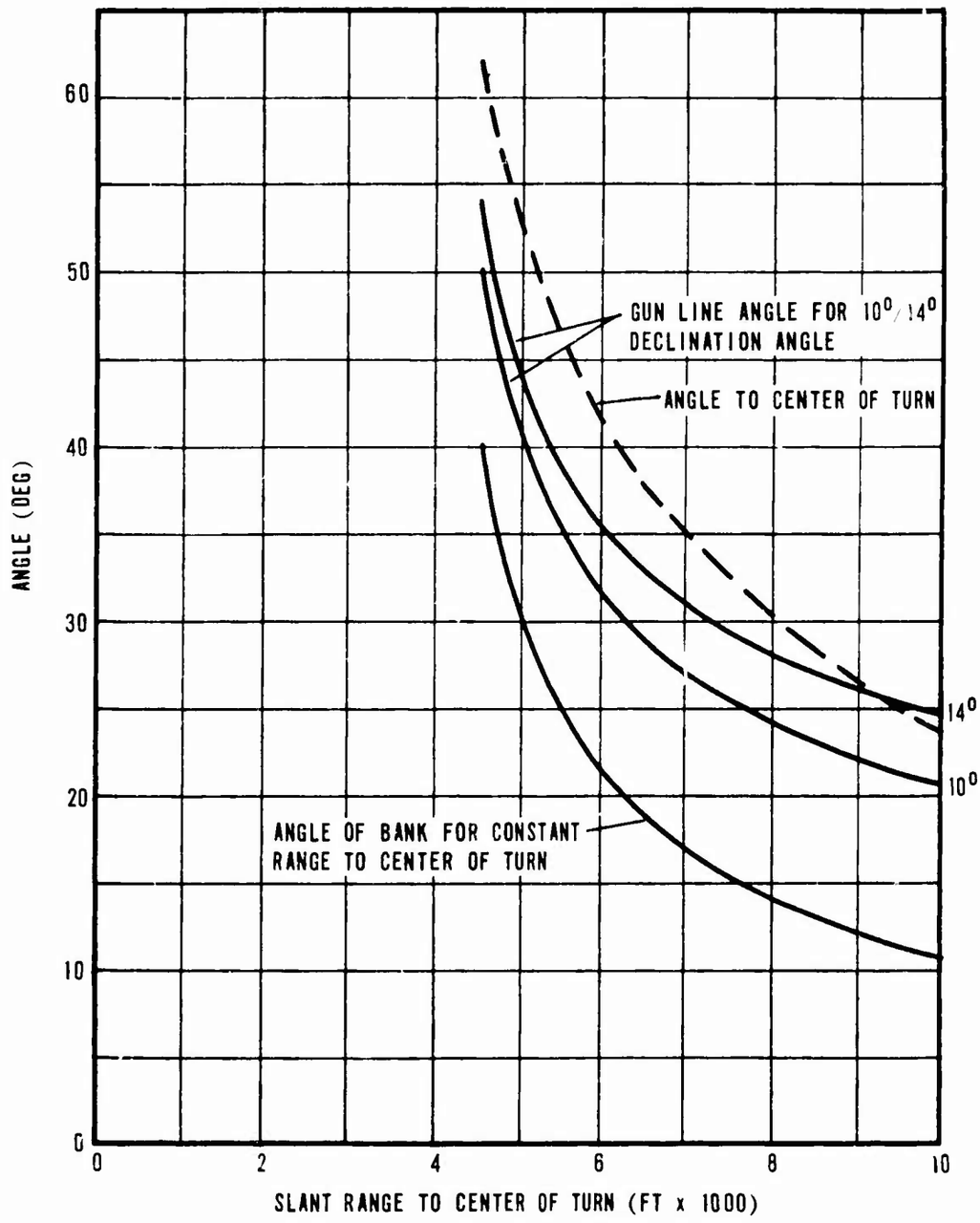

Figure 45. Angle of Bank for Constant Slant Range, Altitude 4000 Ft, Airspeed 140 Kt.

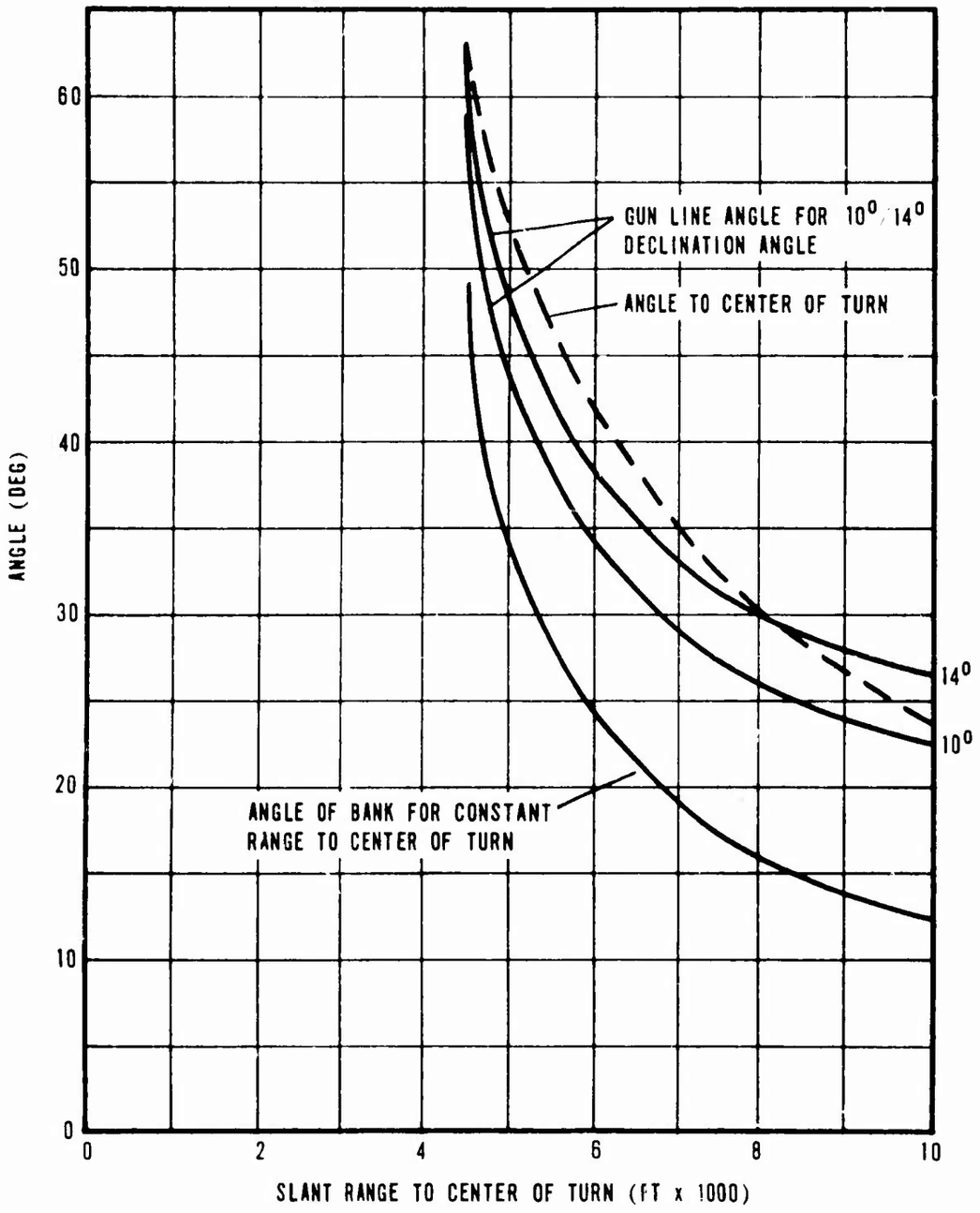

Figure 46. Angle of Bank for Constant Slant Range, Altitude 4000 Ft, Airspeed 150 Kt.

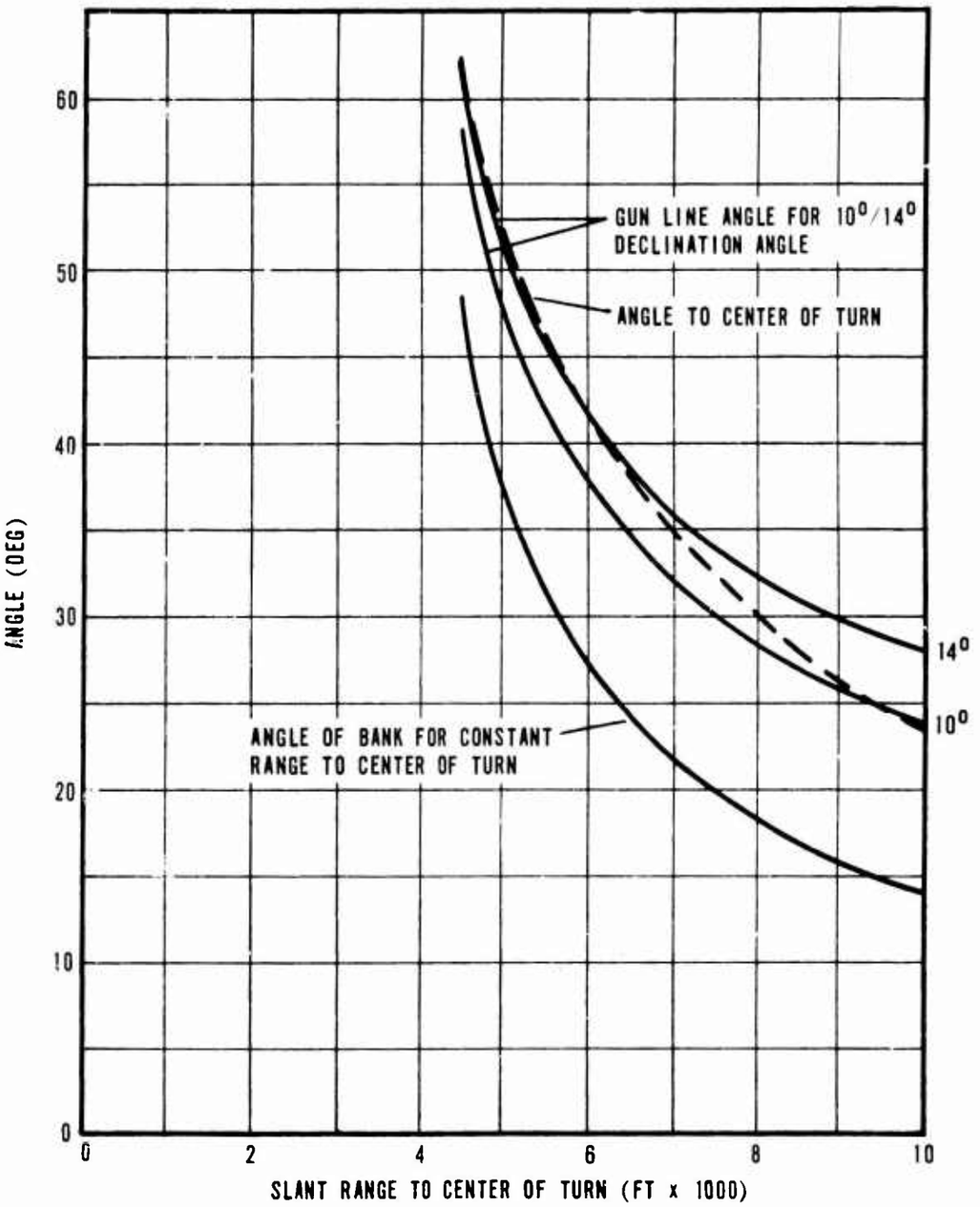

Figure 47. Angle of Bank for Constant Slant Range, Altitude 4000 Ft, Airspeed 160 Kt.

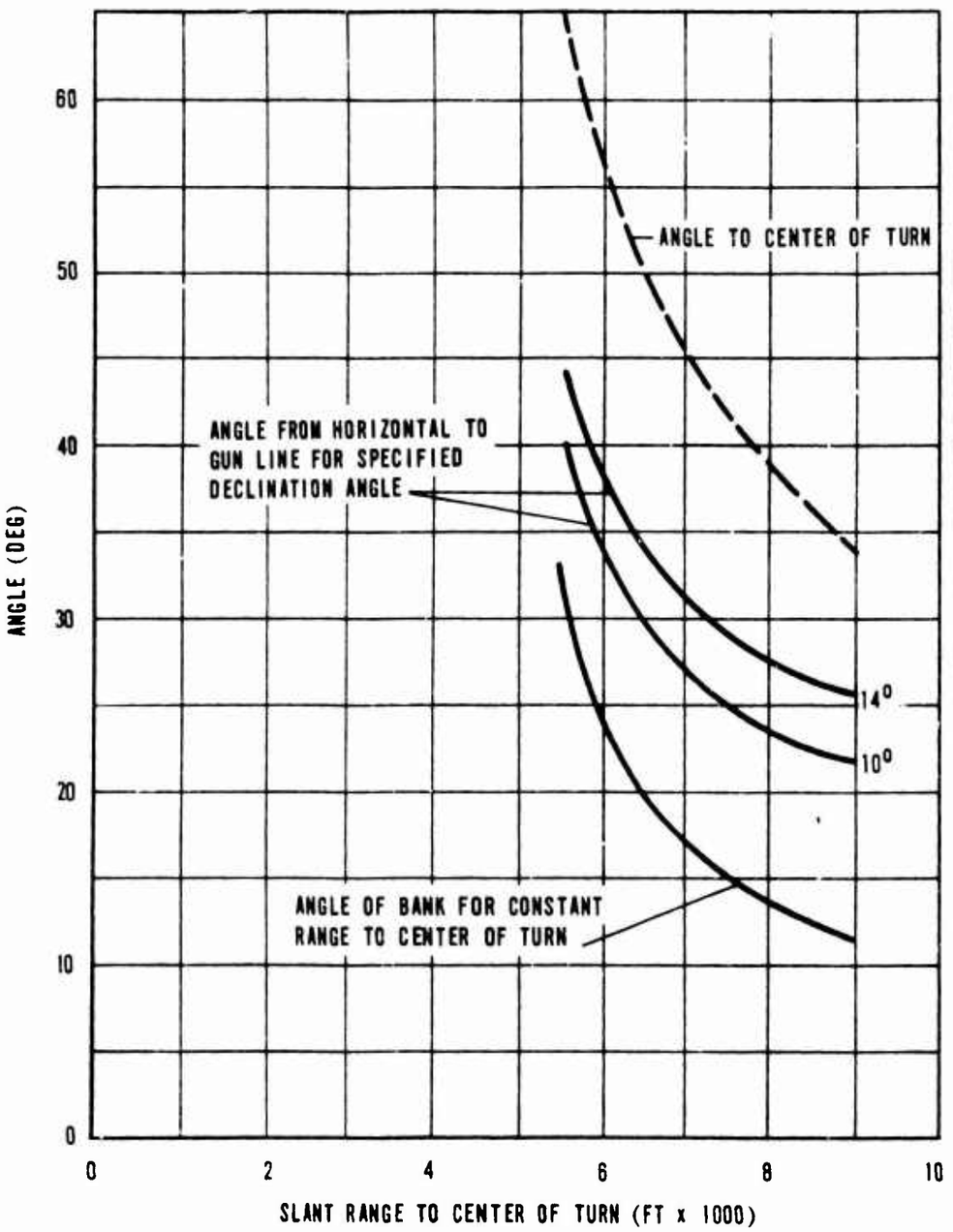

Figure 48. Angle of Bank for Constant Slant Range, Altitude 5000 Ft, Airspeed 130 Kt.

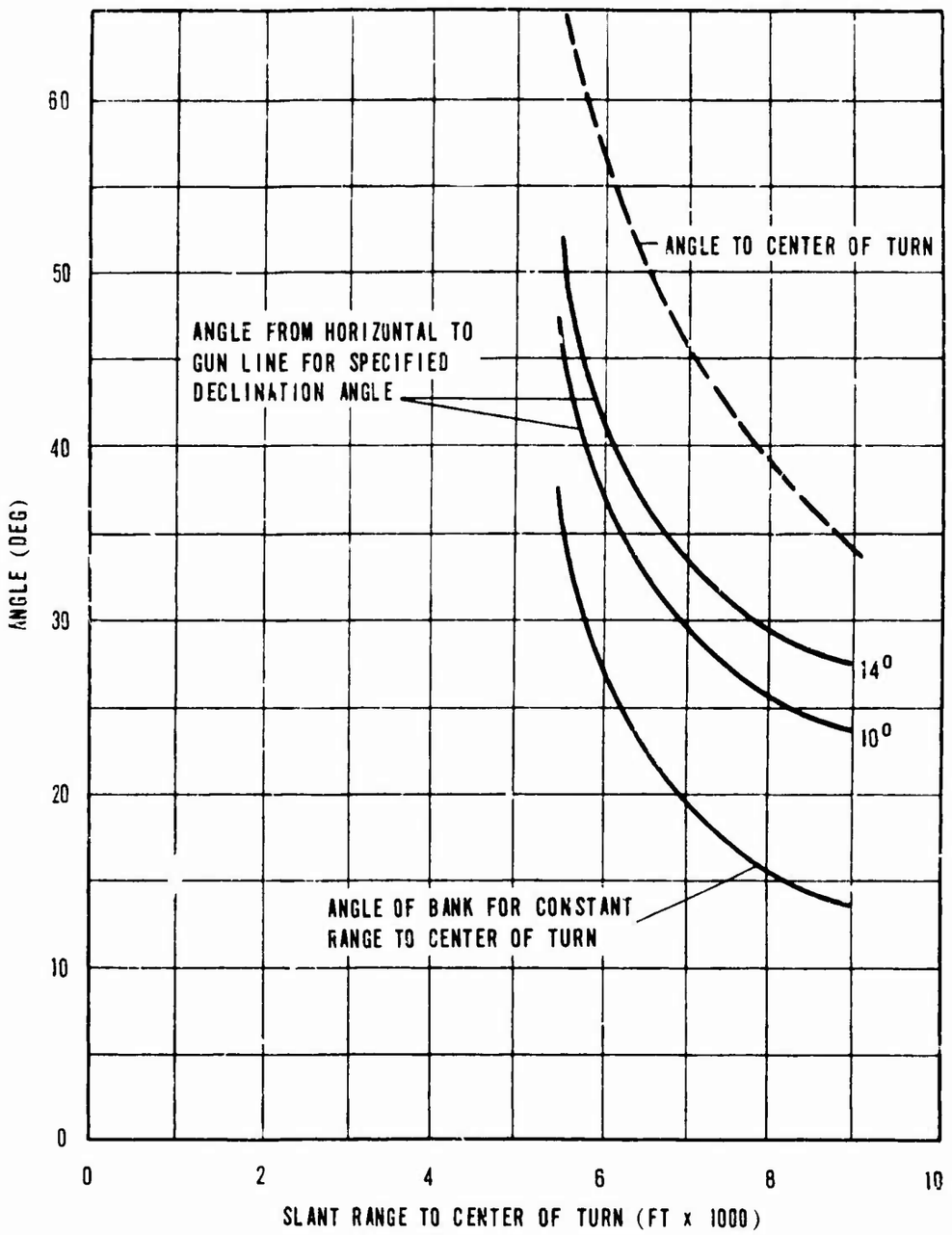

Figure 49. Angle of Bank for Constant Slant Range, Altitude 5000 Ft, Airspeed 140 Kt.

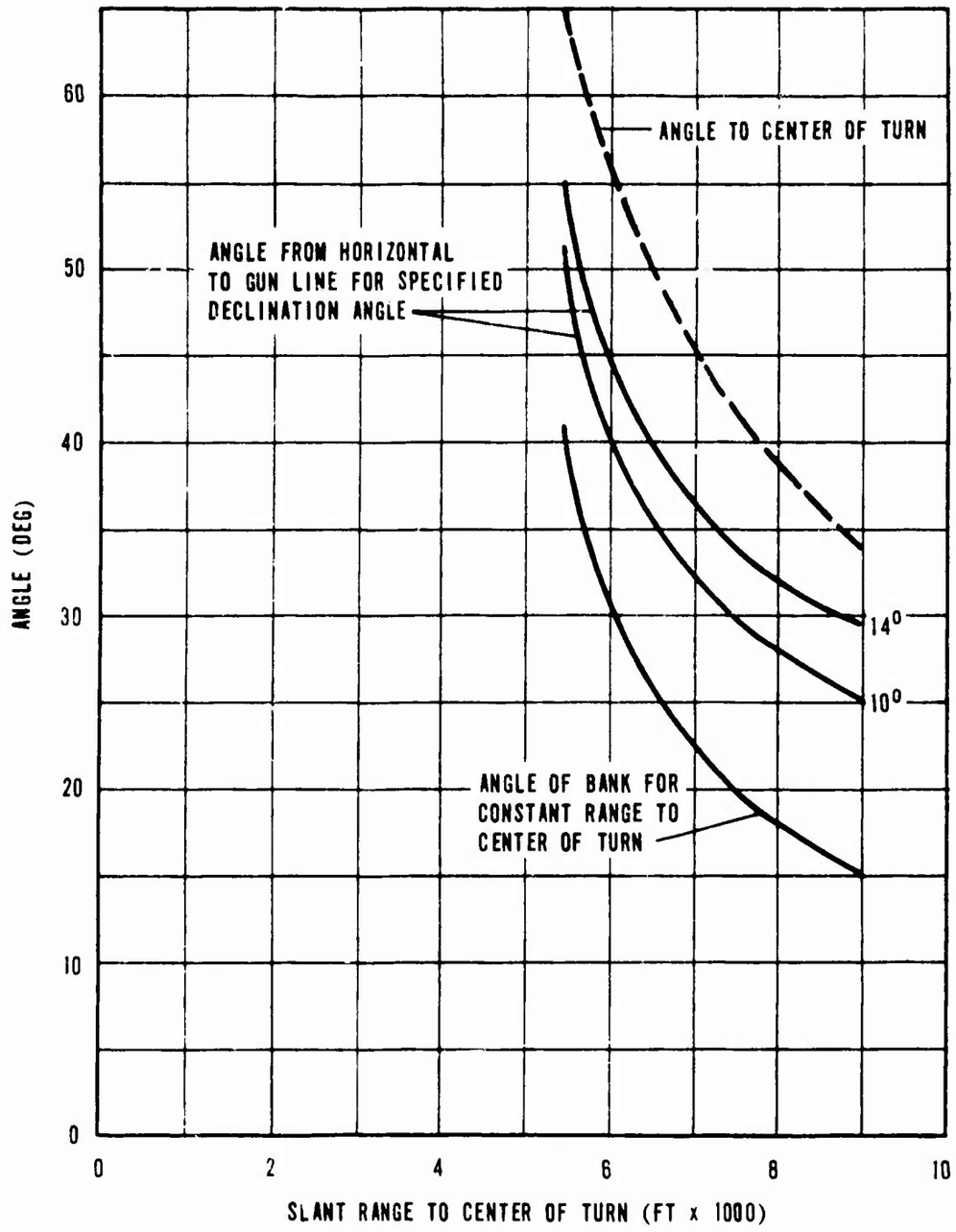

Figure 50. Angle of Bank for Constant Slant Range, Altitude 5000 Ft, Airspeed 150 Kt.

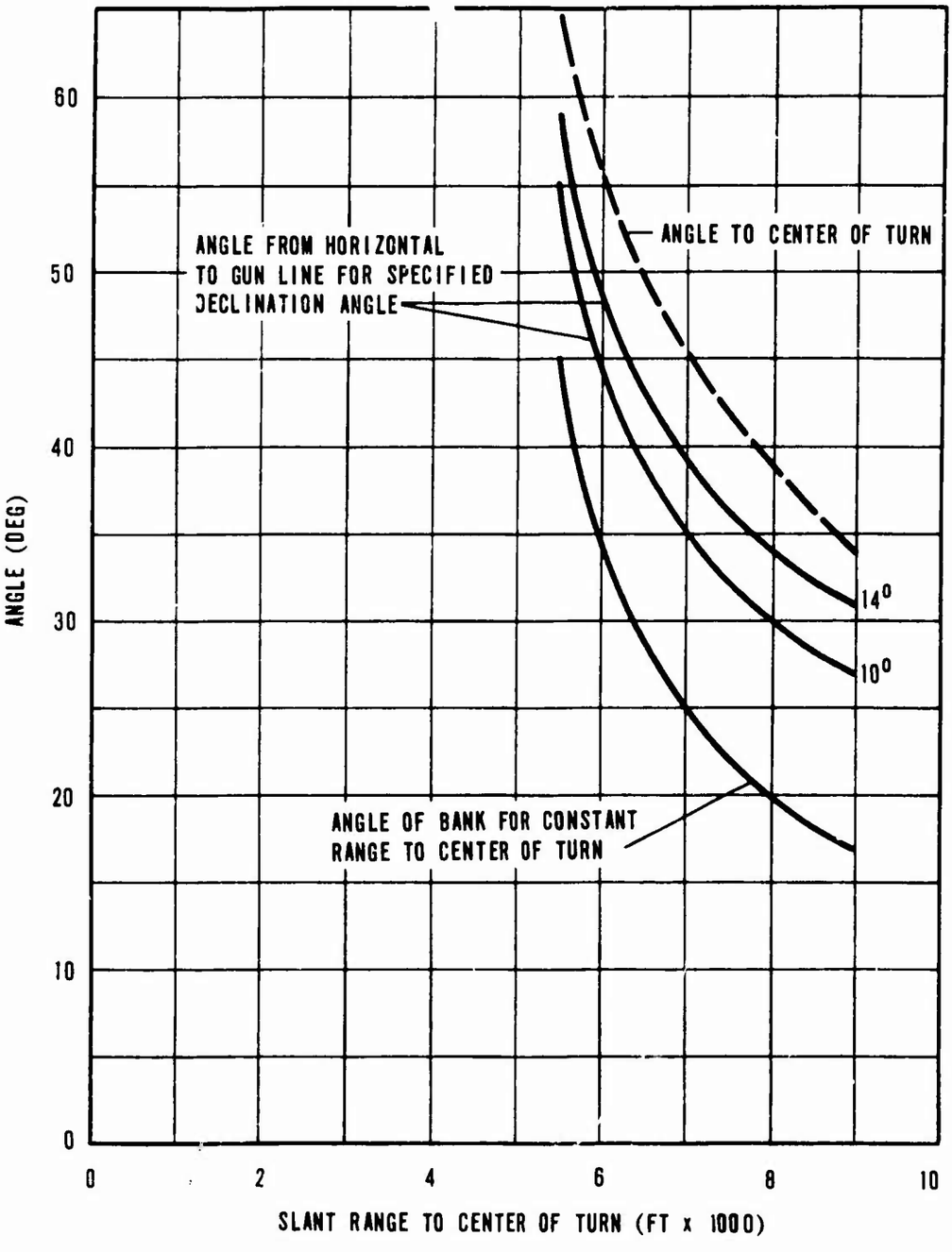

Figure 51. Angle of Bank for Constant Slant Range, Altitude 5000 Ft, Airspeed 160 Kt.

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APPENDIX I

EQUATIONS (SEE FIGURE ON PAGE 3).

It is shown in Bibliography 1 that the relationship between the bank angle θ and the angle to the center of turn Φ for an aircraft in a level turn is given by,

$$\text{Tan } \theta = (V^2/gA)\ (\text{Tan } \Phi) \qquad \text{(I-1)}$$

Where:

θ = Bank angle from the horizontal to the wing line (lateral axis of the aircraft)

Φ = Angle from the horizontal to the center of the turn

V = TAS of the aircraft

A = Aircraft altitude AGL

Equation (I-1) may be rewritten as

$$V = \left(gA \frac{\text{Tan } \theta}{\text{Tan } \Phi}\right)^{\frac{1}{2}} \qquad \text{(I-2)}$$

which gives the airspeed necessary to fly at an altitude A, and bank angle θ, with the center of the turn at an angle Φ from the horizontal. The relationship between the slant range SR, the altitude A, and the angle Φ are as follows:

$$SR = A/\text{Sin } \Phi \qquad \text{(I-3)}$$

or

$$\Phi = \text{Sin}^{-1} \frac{A}{SR}$$

The declination angle Ψ is defined as the angle from the lateral axis of the aircraft (wing line) to the lateral plane containing the gun. From this defination $\theta = \Phi - \Psi$. (I-4)

CURVE SET I

In this curve set, the gun declination Ψ is fixed for each graph. For a given slant range and altitude, the angle to the center of turn (target) Φ is obtained from equation (I-3). Then the bank angle θ is obtained from (I-4). θ, Φ, and A are now substituded into equation (I-2) to obtain the true airspeed required to keep the guns bearing on the center of turn for a given gun declination, slant range, and altitude AGL. In each graph the true airspeed is plotted on the ordinate and the altitude AGL is plotted on the abscissa.

CURVE SET II

Each graph in this curve set has a fixed SR. The curves are generated using the same equations as in set I (i.e., the SR, altitude, and gun declination is set and the TAS necessary to keep the guns bearing on the target is then computed).

CURVE SET III

Each graph in Curve Set III represents a fixed condition of slant range and gun declination. The top solid curve is identical to those of Curve Set I, representing the given slant range. The lower dashed curve is obtained by adding the gravity drop to the angle Φ and recomputing V from equation (I-2) for each value of θ and A. Specifically replace Φ by

$$\Phi' = \Phi + \delta(\Phi, SR) \qquad (I-5)$$

Where Φ is given by equation (I-3), and

δ = Gravity drop, and is a function of Φ and the slant range.

The lower curves then give the airspeed necessary to keep the sight on the target with the sight declinated below the guns by an amount equal to the gravity drop.

CURVE SET IV

In each chart of Curve Set IV, the altitude and airspeed is fixed. In this set the abscissa gives the slant range to the target. The dashed curve gives the angle Φ to the target (center of turn) by equation (I-3). The lower curve gives the bank angle necessary to remain at the corresponding constant

slant range (equation I-1). The two higher curves give the angular position of the gun Φ_g with respect to the horizontal for the two declination angles 10° and 14°. They are obtained by simple adding 10° and 14° to the lower curve.

BIBLIOGRAPHY

1. "Aiming Considerations for Side Firing Aircraft Using Fixed Guns," Armament Memorandum Report 65-36, September 1965, AFATL, Eglin AFB, Florida, by Kenneth K. Cobb.

2. "Gun Settings for Side Firing Aircraft - 7.62 Minigun," Armament Memorandum Report 65-24, July 1965, AFATL, Eglin AFB, Florida, by Kenneth K. Cobb.

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13 ABSTRACT

This report provides information on the sighting of side firing guns for different gun declinations, slant ranges, and altitudes. The information was generated and provided for use in the employment of the AC-47 MINI-gun system and for the design of the follow-on installations.

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Aerodynamic Configuration						
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Change the exponent $(\ )^{\frac{1}{2}}$ to $(\ )^{-\frac{1}{2}}$ (Note: minus one-half) in the equation on page 3.